THE DESIGN OF A HIGH VOLUME MANUFACTURING LINE USING A STRATEGIC MANAGEMENT APPROACH

Subtitle: The design, planning and implementation of the high volume manufacturing line with emphasis on Lean Manufacturing, Total Quality Management and Change Management principles.

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Keywords: Manufacturing Strategy, Lean Manufacture, Quality Function Deployment, Plant and Line Design, Change Management, Thermiculite Production.

ABSTRACT

This thesis examines and develops a proposed manufacturing system methodology and quality control for the design, planning, scheduling and implementation of the Thermiculite 866 high volume manufacturing line, through the use of Lean Manufacturing, Total Quality Management and Change Management principles. The concept under investigation extends to the analysis of flow production benefits and restrictions considering specific characteristics of the product. A novel factory design methodology is proposed to achieve required production volumes and cost effective implementation. Furthermore, high product quality levels are warranted by developing a Strategic Alignment of Quality Function Deployment which brings commercial awareness to the early stages in the product/process development, and reduces the time to market it whilst promoting long-term solutions. The process and the layout design are supported by a proposed Batch/Flow Comparative Matrix. As a result, the proposed factory design methodologies and management of change introduced in the organization led to a successful production system design as well as controlled implementation according to stakeholders requirements. The design and partial implementation of the Thermiculite 866 production line illustrates the effectiveness of the methodology proposed in this thesis to manage and design the equipment and quality for the future Thermiculite production line.

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GLOSSARY

API: American Petroleum Institute

AQL: Acceptance Quality Level

CAD: Computer Aided Design

CEV: Chemically Exfoliated Vermiculite

CFV: Constant Flow Valve

CHP: Combined Heat and Power

DFM: Design for Manufacturing

DOE: Design of Experiments

FMEA: Failure Modes and Effects Analysis

GJ: Giga Joules

HoQ: House of Quality

H&S: Health and Safety

IPPD: Integrates Product and Process Development

ISO: International Organization for Standardization

KPI: Key Performance Indicators

KTP: Knowledge Transfer Partnership

MRP: Material Requirements Planning

NPD: New Product Development

OEM: Original Equipment Manufacturer

PDCA: Plan, Do, Check and Act

PDSA: Plan, Do, Study and Act

QA: Quality Assurance

QFD: Quality Function Deployment

R&D: Research and Development

SAQFD: Strategic Alignment of Quality Function Deployment

SIP: Standardised Inspection Process

SME: Small Medium Size Enterprises

SOFC: Solid Oxide Fuel Cell

SOP: Standards Operations Procedures

SPC: Statistical Process Control

SWOT: Strengths, Weaknesses, Opportunities and Threats analysis

TQM: Total Quality Management

TRIZ: theory of inventive problem solving

WPUA: Weight per Unit Area

5S: Sorting, Straightening, Systematic cleaning, Standardizing, and Sustaining

LIST OF PUBLICATIONS

Refereed Conference Publications

Yumbla[1], R., Lumley, S. & Khan, M. (2011). The Strategic Alignment of Quality Function Deployment (SAQFD) as a key driver for the design of a high volume production line. *26th International Conference on CAD/CAM, Robotics and Factories of the Future 2011*, V1, 371-378

Yumbla[2], R., Lumley, S. & Khan, M. (2011). Innovative methodology for designing a modular high volume flow line. *26th International Conference on CAD/CAM, Robotics and Factories of the Future 2011, V1, 379-387*

In-Press Journal Publications

Yumbla[2], R., Lumley, S. & Khan, M. (2012). Innovative strategic planning for the design of a high volume production line using Quality Function Deployment and a batch – flow production analysis. *International Journal of Customer Relationship Marketing and Management (IJCRMM)*

CHAPTER 1

INTRODUCTION AND PROJECT SCOPE

1.1. Introduction to the Thermiculite 866 Project

The Thermiculite 866 project provides an opportunity for implementing an equipped paced flow manufacturing line with an investment of £0.5M by 2015 at Flexitallic Ltd. The project, which was initiated by a KTP between Flexitallic and The University of Bradford (UoB) in 2010, aimed to increase the current Thermiculite 866 production capacity. After the UoB terminated their mutual agreement with Flexitallic Ltd on March 2011, the project was supervised entirely by Flexitallic.

The existing reduced laboratory batch manufacturing process has already been running at Flexitallic United Kingdom from 2008, although, the future production line requires a different continuous flow approach, as will be explained in Chapter 5. Flexitallic has been developing their novel Thermiculite 866 material and has demonstrated its unique properties in industries such as petrochemical, automotive and Solid Oxide Fuel Cell (SOFC).

1.2. The Flexitallic Group and Gaskets Industry

The Flexitallic Group is the international leader in the design, manufacture and supply of high quality industrial static sealing products, with principle manufacturing operations in USA, England and China. Flexitallic has been developing novel materials such as Thermiculite 866 for high temperatures and chemically demanding conditions. Flexitallic has built on a legacy of innovation with revolutionary product materials such as Thermiculite® and Sigma®. Flexitallic has a global customer service network of owned manufacturing facilities, manufacturing licensees and distribution network, with over 750 distributors in 30 (Flexitallic, 2011). Historically, there has been development of new materials from the compressed asbestos fibre sheet material which used to be the material of choice for "soft" gasket materials. Eventually, asbestos gaskets were regarded as easy to use and very tolerant of abuse, for which it was recognised as very "forgiving". Consequently, the material was used to seal almost all common applications, and usually gave reasonable sealing performance.

A broad experience of asbestos material was established over many years amongst manufacturers and users alike. More recently, with the tendency away from the use of asbestos fibres, a new generation of asbestos-free substitutes has been developed by the sealing industry. This has created an enormous challenge, because only limited experience is available for the new materials in service. Many of the new materials provide improved levels of sealing performance, although their applicability is more limited than the asbestos-based alternatives. Equally, handling of these new materials requires more care in general (European sealing association, 2009)

The health hazards caused by asbestos have promoted the necessity to work out emergency measures and develop new materials of a substitute for asbestos gasket material. Asbestos has been widely used to prevent leakage in high temperature applications, and a substitute material was required for those applications. In the field of gaskets and packing, asbestos production was scheduled to be banned completely by 2008. In addition, the development of substitutions is under way without the establishment of evaluation methods for safety and reliability. Under these circumstances, the development of non-asbestos products with the same performance and ease in handling is desired. Non-asbestos products have limited heat resistance because they generally contain rubber such as one variations of the Thermiculite the 835. One of the options is Thermiculite 866 which is comprised of thermally and chemically restructured vermiculite, non-asbestos, versatile, non-toxic, non-hazardous mineral, Thermiculite® demonstrates remarkable versatility. When combined with various other materials such as aramid or steatite. Thermiculite® is specified by name throughout industry.

Applications of Thermiculite 866 include petro-chemicals, fertilisers and Original Equipment Manufacture (OEM), all of which require high temperatures resistant materials. Flexitallic team of engineers use the versatility of Thermiculite® to create several sealing configurations in equipment and piping systems to increase operational up time for our customers. This remarkable product has proven itself as an effective long-term sealing solution in over 500 of the most demanding industrial sealing applications (Flexitallic, 2011).

One of the most promising applications of the Thermiculite 866 is in the SOFC industry which is been developing novel technology for at least the last ten years. Several universities and companies around the world have been testing Thermiculite 866 in their experimental SOFC technology.

1.3. Solid Oxide Fuel Cell Technology

Fuel cells are electrochemical energy conversion devices with high efficiencies and low carbon emission levels. A typical fuel cell is composed of a porous anode, a porous cathode and a dense electrolyte. The shape and area of the anode and the cathode depends on the size and temperature of the SOFCs. The electrolyte is a pure ionic conductor that allows only ions such as oxygen ion, proton, OH^- and CO_3^{2-} to pass through. SOFCs that operate at high temperatures have the advantage that both hydrocarbons and H2 can be electrochemically oxidized at the anode (Youmin, Ran,

& Zongping, 2010). These components are stacked to produce enough electricity and heat to be recovered.

This technology has several sealing requirements that need to be accomplished: the sealing materials must be thermo-mechanically and thermo-chemically stable in both oxidizing and wet-reducing environments at 800 ◦C for long-term exposures (500–1000 h) (Smeacetto, Salvo, Ferraris, Casalegno, Asinari, & Chrysanthou, 2008). According to Song (2002), conventional high temperature SOFCs operate at 800 to 1000 Celsius. However, such high operation temperatures introduce several problems, such as sintering of the electrodes, degradation of cell materials and limitations in selecting interconnecting materials. The reduction of the operation temperature to intermediate-to-low temperature range (500e800 C) may effectively solve the cell degradation problems and accelerate the commercialization of SOFCs technology (Youmin, Ran, & Zongping, 2010). For this reason, this is the strategy of several SOFC developers. Smeacetto (2008) claims that five main approaches are being studied for sealing SOFCs Fergus (2005) & Weil (2006): brazing, compressive seals, glass, glass–ceramic and glass-composite seals. Flexitallic comes into the scene with the Thermiculite 866 sheet as a compression seal for SOFC. Furthermore, the SOFC market needs an effective economic solution with reduced prices considering that other technologies, such as gas boilers, have defined a low price reference for heating appliances where SOFC might find their market.

1.4. Thermiculite 866 - A Service Proven, High Temperature, Compression Gasket for SOFC Applications

During the development of non-asbestos sealing materials, Flexitallic developed over a number of years a range of sealing materials that are based upon novel technology that does not depend upon the use of fibrous material of any type. Instead it is based upon the use of extremely thin, flexible plates of the natural mineral vermiculite where each crystal plate is nanometres thick and similar to mica in appearance. These plates are obtained by the exfoliation of the mineral by a chemical process into the individual plates which together form the flakes which characterise the mineral.

Vermiculite is a member of the phyllosilicate series of minerals which also includes steatite, also known as talc, and mica. It therefore has all the properties, temperature resistance, chemical resistance and electrical insulation, for which mica is noted. The combination of steatite, a very soft mineral, with the Chemically Exfoliated Vermiculite (CEV) results in a soft sheet material that compresses under modest loads and this means that on assembly of a connection it conforms easily to the surfaces thus forming a seal (Flexitallic, 2010). However, there are two leakages types for a compression gasket, interfacial and internal. The interfacial type is the leakage that occurs between the gasket surfaces and the surfaces to be sealed and the internal type is the leakage through the body of the gasket. In both cases, if the width of the gasket, known as the land width, is too low then the leakage rate will increase for a given surface stress. The consequence can be seen when reducing the land width of gasket over the range of 15mm to 2mm.

Thermiculite 866 was designed specifically as a compression seal for SOFCs. Thermiculite can work in a range of applications and comprised of thermally and chemically restructured vermiculite which is a non-asbestos, versatile, non-toxic, non-hazardous mineral. Thermiculite is the result of combine various materials such as aramid or steatite which improve material capability up to 1000°C and passes the API 607 fire test (Flexitallic, 2010). Thermiculite is specified by name throughout industry. Applications include petro chemicals, fertilisers and OEM, all of which require extreme process temperatures. In addition, Flexitallic team use the versatility of Thermiculite to create bespoke sealing configurations in equipment and piping systems to increase operational up-time. Thermiculite 866, which is one of the type of materials, is easy to cut into gaskets, ones of simple shape can be cut with a knife or with scissors, whilst complex ones can be readily cut using the traditional steel cutters such as are routinely used to cut industrial gaskets from soft sheet material. Following some information extracted from the official Thermiculite 866 brochure:

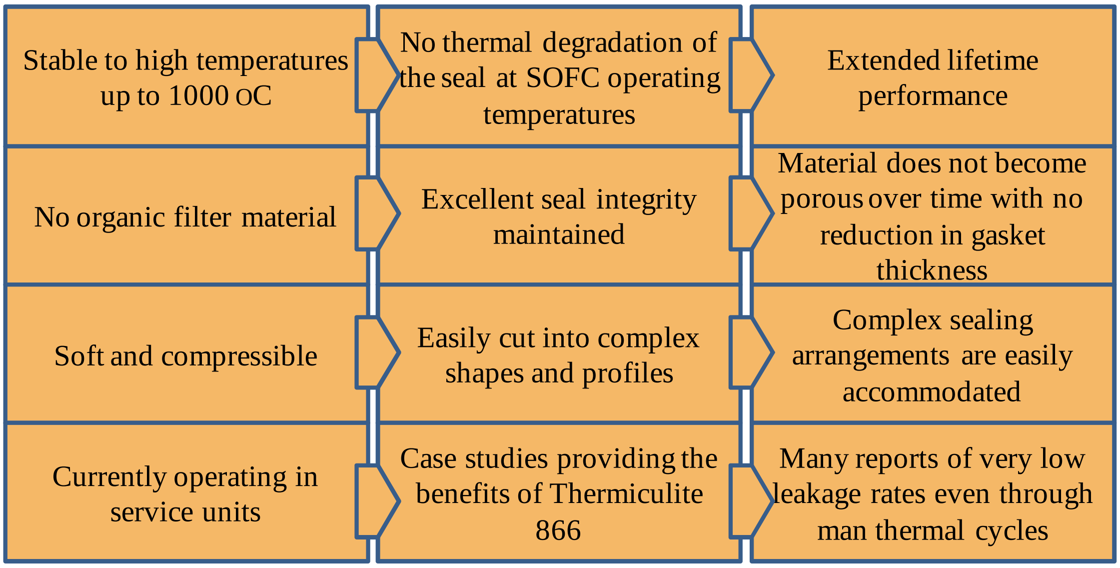


Figure 1.1: Thermiculite 866 Properties

Resource: (Flexitallic Group, 2010)

Thermiculite 866 is based upon CEV, which is a naturally occurring mineral closely related to mica. Vermiculite consists of a stack of very many crystal plates that can be exfoliated to separate the crystal plates. The exfoliation can be done by application of heat or chemical exfoliation. The separated plates can be highly flexible and other affine materials can be added to produce a flexible material. Figure 1.2 shows vermiculate crystal plates:

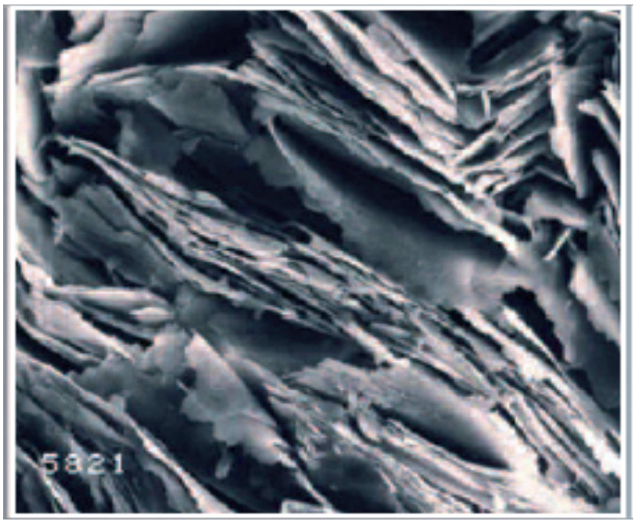


Figure 1.2: Crystal Plates Vermiculite Structure

Resource: (Flexitallic Group, 2010)

The combination of vermiculite and other key material produce a very flexible sheet material ready to cut into gaskets of complex shapes. Figure 1.3 shows a side view section of a 1 mm sheet that has been produced according to the manufacturing process explained in Chapter 5.

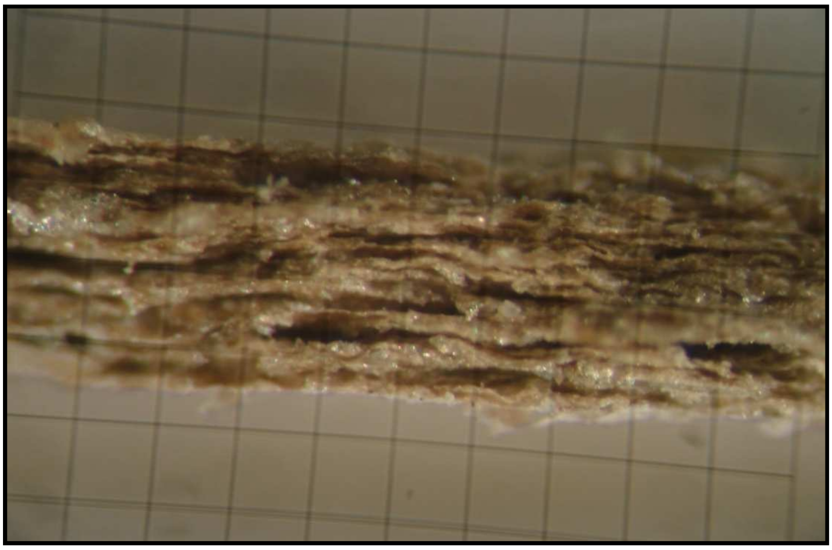


Figure 1.3: Thermiculite 866 Layered Structure

Resource: (Flexitallic Group, 2010)

1.5. Thermiculite 866 Service to Industry

Thermiculite 866 is designed completely free of organic content for SOFCs because any organic material would produce contamination and degradation of the cell. This material characteristic ensures that during the lifetime of the fuel cell there is no increase in porosity or additional leakage. Figure 1.4 shows two examples of gaskets cut for planar design SOFC applications.

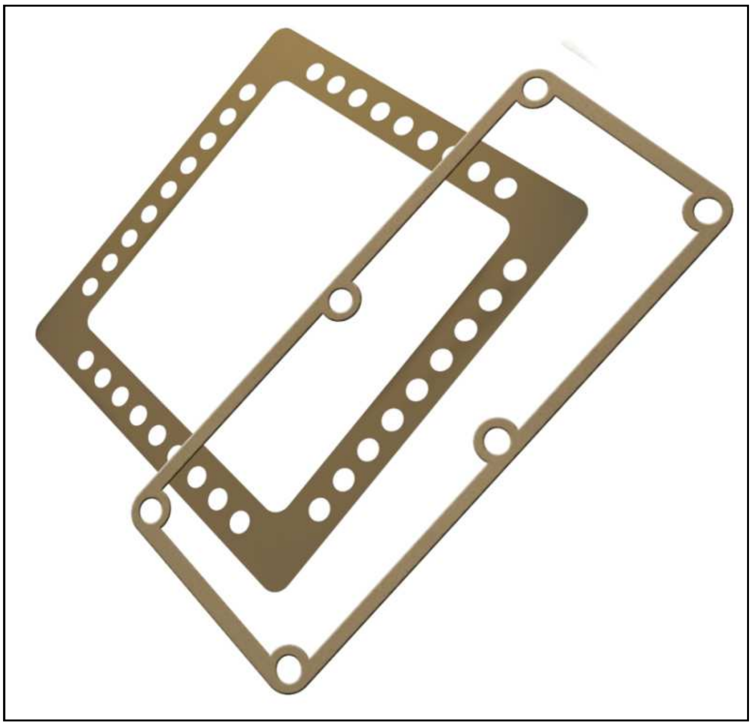


Figure 1.4: Cut Gaskets with Thermiculite 866

Resource: (Flexitallic Group, 2010)

Thermiculite 866 has succeeded in field trials and laboratory tests. Thermiculite 866 performance can be characterised by parameters used in the sealing industry such as leak rate at a specific temperature. For example, Figure 1.5 shows the sealing Curve for Thermiculite 866 of 0.92mm at 600C.

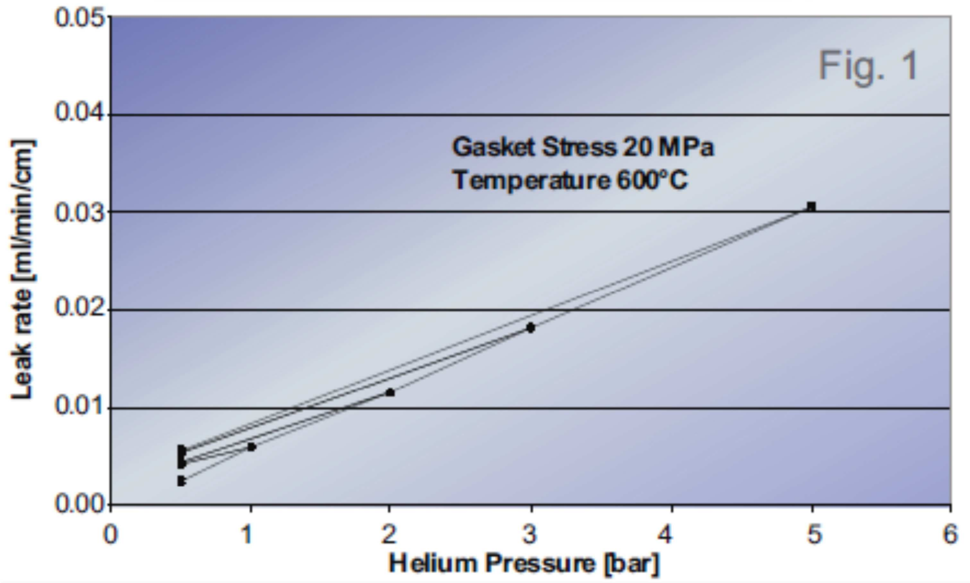


Figure 1.5: Sealing Curve for Thermiculite 866 of 0.92mm at 600 C

Resource: (Flexitallic Group, 2010)

The sealing curve above is similar to the leak rate experienced at 25 C. This demonstrates the consistency of Thermiculite 866 when exposed to high temperatures. Furthermore, the material demonstrates to remain stable during thermal cycling at 600 C. In fact, TH866 achieves up to 75% Index of leak rate at more than 20 thermal cycling with air and fuel. This is an extensive result comparing against rigid seals such as glass, glass-ceramic or braze which possess less resistance to cycling.

1.6. Thermiculite 866 Commercialisation Plan in the SOFC Industry

There are few market conditions that promote the development of SOFCs for the UK and the Western Europe market. Figure 1.6 displays the historic of heating appliances demand during the last six years in Europe, and it shows an average demand of 12 million units per year. Considering that SOFC introduction would potentially take the Micro CHP market which is only 10% of the heating appliances market. Furthermore, considering there are no more than ten major players in the SOFC industry, we might conclude that 1% of the total market would be absorbed by each SOFC competitor during the first introduction year. Flexitallic will fully provide sealing SOFCs solution to one specific UK Company. In other words, Thermiculite 866 production line needs to be able to produce at least enough Thermiculite 866 sheets for 80,000 to 120,000 SOFCs units for the first year after launch and commercialization of the SOFC for house usage.

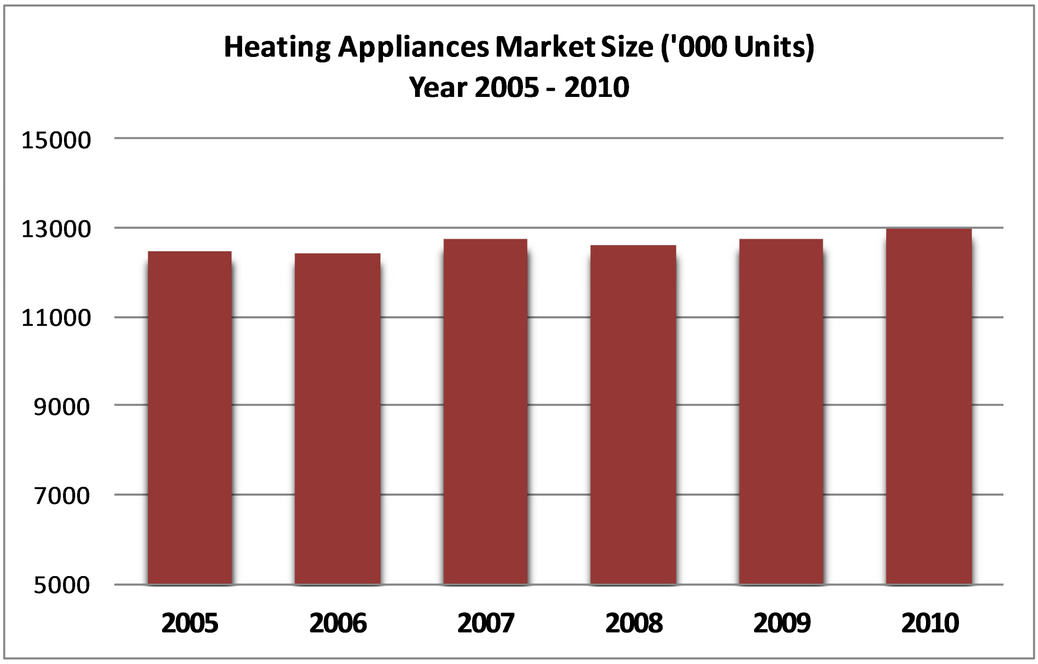


Figure 1.6 Market Sizes Historic Retail Volume

Source: Euromonitor International (2011)

In fact, there are additional encouraging facts that would promote a greater introduction of SOFCs units in the Europe market and in the UK in particular. The UK market is a good niche for alternative and "green" technology for heating appliances. The residential consumption of gas in the UK was 1314.1 mn Giga Joules (GJ) in 2010 which is within the top 5th in the world and means a 40% more consumption than China internal consumption, there is a huge motivation for introduce more efficient heating technology at UK homes. In fact, the UK posses the

3rd place in the world in Residential Consumption Gas Per Capita which is 21.2 GJ/Capita. Furthermore, the UK is the 9th highest country in residential consumption of electricity (117.4 mn KWh in 2010) (Euromonitor International, 2011). These conditions and other incentives such as the export of electricity to the grid from small Combined Heat and Power (CHP) movement scheme are major economical drivers for the development of SOFC devices to heat domestic water and produce electricity at home.

After considering the forecasted demand for the next five years and the stage of SOFC development in a UK leading company, the required high volume production line must support a production quick increase for 2016, and warranty supply of Thermiculite 866 sheets for part of the UK SOFCs market that is projected to be 1,600,000 per year (Delta Enargy & Enviroment, 2010). Worldwide, several organisations that are developing planar SOFC and that are targeting the use of their products in the residential CHP market and auxiliary/remote/secure power markets are using Thermiculite 866 to solve their fuel cell sealing requirements. One particular developer has suggested that the market opportunity is huge considering the global annual ‘boiler’ sales >30m/a – Goldman Sachs. Furthermore, “Over 6 million fuel cell CHP units installed by 2020 (30% of the market…)” (Hurth, 2009).

Considering the Ansoff Matrix (The Times, 2012) categories and the facts previously mentioned, it is possible to conclude that Thermiculite 866 fits into the diversification market strategy. Thermiculite 866 needs a growth strategy to be introduced in the new SOFC market. Global SOFC market to reach £160,400,000 by 2015, according to a new report by Global Industry Analysts, Inc. SOFC is an industry with great potential and is of enormous importance in the wake of rising energy consumption and limited natural resources. In addition, as discussed above, the UK potential SOFC market is encouraging considering the levels of domestic gas and electricity consumption in the UK.

The plan to achieve the objectives and facilitate the strategy is by continuing the product development and promoting Thermiculite Range with universities around the world and other SOFCs developers. Some of these Thermiculite Range products have been in the industry for more than five years, and require to be introduced in the SOFC market with marketing strategies. For this reason, the marketing initiatives have been cascading downstream in the different organizational silos. For example, Applications and Research and Development (R&D) have been contacting key players in the SOFC development.

1.7. The Thermiculite Project and Thesis Scope

Previous sections explain the Thermiculite product features and the viability of the project based on the future SOFC demand. This thesis aims to produce methodologies for the implementation of the Quality Assurance (QA) system for Thermiculite production line whilst managing the implementation of a high volume production line at Flexitallic Ltd. This approach does not intent to set hurdles in product development, to define a mechanism to integrate QFD, Plant Design and Project Management. This holistic approach aims to deliver a simplified methodology to be applied during product development in Small Medium Size Enterprises (SMEs). Finally, the utilization of the Thermiculite 866 as a case study will permit to bring in context the utilization of the proposed SAQFD and related management.

The proposed project management methodology, which includes an innovative chart to evaluate batch and flow line production systems, will be extended for the utilization during New Product Development (NPD) in SMEs. The proposed methodology should promote the application of concurrent engineering practices and lean manufacturing concepts in a tangible way using structured simple methods. Following sections explain specific deliverables for the implementation of the Thermiculite. Section 3.3 includes specific research goals to develop a decision making chart to assist the plant design stage. Finally a novel approach of the Quality Function Deployment (QFD) is developed as fundamental part of this thesis and delivery for the application in a broader utilisation in SMEs. For this purpose, the Thermiculite 866 project is a case research to demonstrate the methodologies developed for the Strategically Aligned Quality Function Deployment (SAQFD) and a project planning that would facilitate the overall implementation of the future high volume production line. It is important to mention that this thesis develops a methodology that copes with the challenges of product development and high volume production requirements in SMEs facing complex market challenges. The validity of the concepts developed in this thesis will be supported on one single case study: the design and improvement of the current Thermiculite 866 production process.

1.7.1. Process Development and Manufacturing Improvement For Thermiculite 866

This research aims where derived through condensation of a KTP programme outline into elements of manufacturing strategy, management of change, lean manufacturing, total quality management (TQM) and Flexitallic protocols which are in line with the research in question. The following highlight gives a concise prologue to the objectives for the Thermiculite line implementation.

The strategic aim of the project is to enable the introduction of new a high volume material process manufacturing line to meet the demands of a significant increase in production rates within a strategic context of increasing cost-effectiveness underpinned by repeatable achievement of manufactured quality of the patented Thermiculite 866 product.

This thesis aims to support the development and implementation of the Thermiculite 866 production line by producing novel managerial and quality control methodologies. All Managerial and Engineering concepts included in this document support the implementation at Flexitallic which provide a great case study to demonstrate its applicability and benefits.

1.7.2. Aims of Research

This research aims to promote good use of resources in SME for design, development and launch new products and guaranty a successful product introduction in the market. This thesis aims to simplify Total Quality Manufacturing (TQM) and concurring engineering practices that have been successful in large companies. This brings multiple challenges to the thesis proposal such as to develop a methodology to integrate plant design and QFD while following a structured planning. In fact, this thesis aims to develop concept into a methodology that can be easily implemented in product launches at SMEs.

First, it is required an innovative factory planning methodology to achieve the objectives defined by Flexitallic for the future expansion of the Thermiculite 866 production line. For this purpose, the concepts under investigation extend to the analysis of flow benefits and restrictions considering product features and demand addressed in the proposed Batch / Flow Comparative Matrix. This decision support chart assist in defining the plant design based on the evaluation of aspects such as demand and product feature. This innovative decision support chart is an important section of the overall product design and project management of the project.

Furthermore, the research introduces a novel QFD to support the manufacturing line design using a mechanism of incorporation commercial awareness in any stage of the product deployment. The classic QFD ensures process planning by bringing parts deployment into parts characteristics through the House of Quality (HoQ). This study renews the original QFD by developing the Strategic Alignment of Quality Function Deployment (SAQFD) to achieve active management of Houses III and House IV. The design of SAQFD is based on Novel-QFD approaches that have been proposed during the last ten years. In the SAQFD practitioners identify opportunities prior applying structured methodologies to develop an optimized product definition. This thesis proposes a structured methodology to apply the proposed SAQFD in product and process development. The development of a planning scheme that includes the proposed SAQFD and comparative matrix constitute another important achievement of this thesis. Finally, the SAQFD applicability is demonstrated during the design and partial implementation of the Thermiculite 866 high volume production line which is the unique case study for the proposed methodology.

1.8. Structure of Thesis

This thesis consists of six chapters and three appendices. The thesis framework is based on real requirements of the Thermiculite 866 project and academic research to support QA and high volume production requirements. The sections in the thesis follow a logical sequence starting with a background which is followed by research and application of a new project planning.

- Industrial background and future requirement in Chapters 1 and Chapter 2
- Research approach and theory building are presented in Chapter 3
- The Thermiculite 866 case research is developed in Chapter 4 and Chapter 5

- Research conclusions are discussed in Chapter 6

Next section describes in detail each chapter:

Chapter 1 covers the introduction to the research, description of the project challenges regarding the SOFC technology and commercial justification for the project implementation. This chapter mainly focuses on the characteristics of the Thermiculite 866 and its advantages as a sealing solution for the SOFC.

In Chapter 2 the emphasis is to define a theoretical support for the development of a novel plant design and management methodology for the Thermiculite 866 project. This literature review chapter explains concepts of the QFD and its development during the last twenty years. In addition, this chapter includes concepts and methods for plant and lay out design. Finally, this section refers to two papers which are the first intent to develop an integrated approach of QFD and planning for production systems.

Chapter 3 defines the requirement for a new approach to implement quality in product/process development stages. This is the core of the thesis where a novel QFD approach is explored and defined based on literature presented in Chapter 2. Furthermore, this chapter exposes author's views and logic to define the so called "Strategic Aligned Quality Function Deployment" (SAQFD).

Chapter 4 covers an in-depth understanding project management and the required management of change to success in the implementation of the the proposed work force alignment and strategic alignment for the application of SAQFD. This chapter proposes two corner stones of the project research and line implementation: the project team structure and the batch/flow comparative matrix. This proposed technique provides a first insight of future requirements to adopt a continuous flow line layout and project planning based on conceptual design followed by analysis and implementation.

In Chapter 5, the manufacturing process of the Thermiculite 866 is developed from the practice of the Strategic Alignment of QFD which provides a solid base for Plant Layout design. This chapter constitute the case research to support the SAQFD theory development. In addition, the author proposes a project planning and management initiative to cope with the new requirements of bringing the novel SAQFD. This chapter includes some proposals to increase the capacity of the drying process, which is the manufacturing bottle neck and possibly high energy consumption in the future. Finally, among other important processes for product quality, the mixing process in improved because its importance for the product quality.

Chapter 6, discusses conclusions of the thesis including the importance and benefits of the SAQFD and Batch/Flow comparative matrix for the design of a high volume production line. The introduction of new project management techniques require change management to support the organization in the improvement journey and three major incremental changes are exposed in the conclusion.

2. CHAPTER 2

REVIEW OF THE LITERATURE

Considering the aims of this thesis, the Literature Review needs to be directed to cope with the management requirements in projects in SMEs. The material in this chapter is material from literature and methods used in large manufacturing enterprises that have a noticeable influence on the operation and manufacturing. In addition, this chapter introduce several concepts of management to perform well during product launch and production. Finally, this chapter explores the theoretical base and justification to redefine a novel QFD and its management during product launches.

2.1. The Management of Change

Organizations change all the time, and this process, for most part, is unplanned and gradual. According to Burke (2002) the external environment now changes much more rapidly than organizations do. Organizations today are playing catch-up and certainly this will be true even more so in the future. As a matter of fact, Foster and Kaplan (2001) claim that capital markets change far more rapidly than corporations do because of discontinuity, they weed out poor performers and so forth. Usually these changes consist of fine-tuning such as installing a new system for sales management, initiating a program to improve the quality of products and/or services. After the need for change has been defined, it is important to define the language used to define change which is as follows: revolutionary vs. evolutionary, discontinuous vs. continuous, episodic vs. continuing flow, transformational vs. transactional, strategic vs. operational, total system vs. local option.

An organization that needs change in mission and strategy means that the organization's culture must also be changed. This implies change of people's behaviour instead of culture that facilitates or prevents transformation. For this purpose, Thermiculite 866 project intents to be an example of continuous evolution in the total operational system at Flexitallic. In addition, the implementation of lean manufacturing concepts in the design of the new Thermiculite 866 high volume production line is a big challenge in Flexitallic.

When aiming to understand suitable development strategies, it is appropriate to recognize their strong links with the organization culture. This can be conceptualized as the deeper level of basic assumptions that are shared within an organization that operates unconsciously in its views. The original founders of many of today's companies played a crucial role in establishing their overall strategy and organization culture. According to behavioural theories (neoclassical, entrepreneurs, under conditions) strategies are not given, but need to be constructed by senior managers. When internal and external environmental is not known they have to select particular problems and priorities and bring into play particular areas of information and knowledge in order to make decisions. When organizations exhibit various degrees of uncertainty, then decision-making is about judgements and interpretations as much as about logical deductions (Clark, 1995).

There are eight items proposed by Kotter (2002) to achieve success in organizational change: increase urgency, build the guiding team, get the vision right, communicate for buy-in, empower action, create short-term wins, don't let up and make change stick. Considering a technical view, Brown (2009), suggested that designer teams should expect to move through three overlapping stages over the course of a project: an inspirational space, in which insights are gathered from every possible source; an ideation space, in which those insights are translated into ideas; and an implementation space, in which the best ideas are developed into a concrete, fully conceived plan of action.

2.1.1. Knowledge Transfer Partnership as a Driver of Change in Manufacturing Companies

Knowledge Transfer Partnership (KTP) is a government initiative and is funded by a number of public sector organisations ("the sponsors") with the policy and administrative arrangements led by the Department of Trade and Industry (DTI) which currently provides approximately 75 percent of the total funding. This government scheme focuses on technology transfer and training (Jones, 2001) with the aim of effecting organisational change (Peattie, 1993).

This ideal mutual benefit of universities and organizations might be frustrating to both sites of the partnership. In fact, the result is often disillusionment for the academics through excessive training and consultancy with a lack of systematic research outcomes (Van Dierdonck, 1988). Similarly, the organisation's personnel can be frustrated at the transient and apparent high level nature of university staff intervention, leading to unfavourable comparisons with more traditional consultants (Fassin, 2000). The KTP graduate, although qualified, is usually lacking in experience when addressing large change issues within the organisation (Henderson, McAdam, & Leonard, 2006). However, the program has proved its effectiveness to train graduates and promote change in SMEs in the UK.

One of the primary changes at Flexitallic Ltd is the implementation of quality programmes and production controls which often lead to major change within an organization. For example, the implementation of quality may represent a strategic move to develop an improved culture of quality. Attaining such level of performance requires an integrated manufacturing strategy. The integrationist perspective of manufacturing strategy should be such that it enables a high level of manufacturing capability transformation into useable capabilities to gain competitive advantage within an organisation's business environment whilst constantly striving to improve those capabilities. With the realisation that manufacturing strategy is such an important role in organisations, and key effect for deploying an integrated framework for realisation need to be understood. To solve this fundamental problem (Ungan, 2006) argues that manufacturing capabilities, such as decisions on cost, quality, delivery and flexibility in the manufacturing system, need to be identified as well as the creation of an innovative organisational culture.

Many firms do not have mechanisms such as strategy formulation and implementation processes, to bring about the desired alignment. Operational decisions are carried out by reference to the firm's "way of doing things" - rules built on past experience, which may not be suited to world class performance. For this reason, most KTP projects promote substantial change to organisation's culture when those are possible to be adopted. People facing cultural change and challenges due to the implementation of KTP projects need to understand this requirement. In addition, there is a need for a clear communication plan and channels to motivate individuals to overcome resistance and to educate senior managers, employees, and customers on the benefits of change and other quality principles such as Six Sigma (Kwak, 2006).

2.2. The Customer Focus and the Product Life Cycle for the Manufacturing Strategy

All products and services have certain life cycles. The life cycle refers to the period from the product's first launch into the market until its final withdrawal and it is split up in phases. During this period significant changes are made in the way that the product is behaving in the market i.e. its reflection in respect of sales to the company that introduced it into the market. Since an increase in profits is the major goal of a company that introduces a product into a market, the product's life cycle management is very important. The product's life cycle period usually consists of five major steps or phases:

a) Product Development
b) Product Introduction
c) Product Growth
d) Product Maturity
e) Product Decline

The Thermiculite 866 is currently in the introduction and growth stages in the product life cycle, and a specific business planning process can be applied to fully launch the product and produce growth. In developing appropriate manufacturing strategy for a manufacturing system, it is imperative to integrate the manufacturing strategy with the business objectives. Corporate objectives lead to marketing strategy. Marketing identifies appropriate markets, product mix, services and the degree to which an organisation needs to customise and innovate hence enabling the integration of a manufacturing strategy that focuses on critical dimensions typically cost, lead-time, quality, reliability, capacity, production control, product features, design capability, human resources, suppliers and distribution. This concept of a 'strategic fit' is central to manufacturing strategy theory (Kim & Lee, 1993). Figure 2.1 shows how to cascade information and objectives from top managerial levels to shop floor.

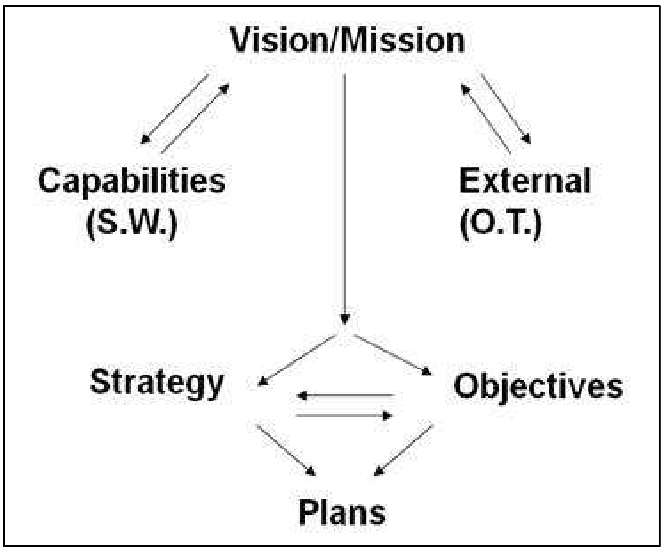


Figure 2.1: Thermiculite 866 Plans Definition

(Knowledge Transfer Partnerships, 2009)

This hierarchical approach proposed in Figure 2.1 is based on usual method to cascade objectives from Vision/Mission to Strategy and Objectives to lower levels linked with the world class Key Performance Indicators (KPI), Section 4.8 covers this aspect of the project. This would cascade plans and objective to engineers and operators. It is important to notice the Capabilities and External Analysis which is basically Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. There are several and more elaborated approaches to manage product development and early marketing strategies. However, this thesis will tackle the issue from manufacturing point of view in Chapter 5.

2.3. Product / Process Development and Resource Management

The Thermiculite 866 project requires various strategic developments considering its current process design and development. For an SME such as Flexitallic immediate priorities and its resources seem to be interrelated. This means that resources would be located in short-term priorities. This is a great opportunity to find mechanisms to improve and defined process with limited resources. The process to bring these ideas from managerial level to engineers and technicians are proposed in the previous section. Although, there are techniques with specific strategies and plans that support two major streams defined after the appreciation of the process development and company culture:

- Use a structured methodology to design and implement a high volume production line considering operators training and Lean Manufacturing implementation.

- The process development must be based on TQM using QFD and other Concurrent Engineering techniques with engineers and technicians.

The major and most valuable asset in the current Thermiculite 866 process comes from the technicians and their inherent know-how and expertise with the product. For this reason, parallel efforts to develop people and process design were conducted during presentations and meetings with different levels in the organization. There are few simple bullet points stated by Brown (2009) to promote experimentation and knowledge sharing for product and process research:

a) The best ideas come from the whole organization and not just designers and engineers (basic principle in concurrent engineering).

b) Individuals most exposed to changing externalities are the ones best placed to respond to experimentation.

c) Ideas should not be favoured based on who creates them. All single individual in the organization is capable of promoting improvement.

d) Ideas that create a buzz should be favoured. Indeed, ideas should gain a vocal following.

e) The “gardening” skills of senior leadership should be used to tend, prune, and harvest ideas.

f) The organization should have a sense of direction and innovators and do not require the need for constant supervision.

In addition, every management efforts should be supported by application of statistical theory to identify and solve problems within a manufacturing context. According to Husband (1997), there are several reasons for the relatively low application of statistical methods in SMEs. However, management in small companies, in general, do not have the sufficient theoretical knowledge to see the potential of using statistical tools. In many cases, they and their employees even become frightened when statistical tools are discussed. Small companies also lack resources in the form of time and personnel. Small organisations tend to have a lean organisation and, therefore, they find it difficult to appoint a facilitator or co-ordinator for the implementation process. Finally, they also have limited resources to provide internal training. Lack of resources in these aspects leads to a need for a careful analysis of which strategy to use when implementing statistical methods in order to succeed (Husband, 1997). Lawrence (2004) claims that “human” interactions works in some companies, but most companies need a systematic methodology to help the development team to identify the required values, balance them, and generate a good design. These observations are key for defining future strategy in project management and future objectives for the Thermiculite business.

2.4. Productivity and Business Strategy Considerations

To effectively cascade priorities from managerial level downwards is important to accomplish specific parameters proposed for manufacturing such as productivity. The productivity on the shop floor can be identified by six factors:

a) Planned Production Times.

b) Physical Working Conditions.

c) Economic Working Conditions.

d) Degree of Centralization for Decisions.

e) Acceptance of Responsibility.

f) Attitude Towards Time.

(Bruijn, 2006).

Indeed, some companies fail to recognize the relationship between manufacturing strategies, such as productivity improvement, and corporate strategies. In the case of Flexitallic, some of the intentions to improve the capacity by increasing capacity of mixing and intensive manual handling are not well driven for a high volume production line where quality is the major requirement in this case. In addition, according to from the perspective of cost competitiveness expensive control equipment will not be sufficient to obtain quality if those are not well driven according to the real relationship of process parameters and product features. In fact, maximising of innovation in the right tooling and equipment across a business can provide the best company results if it is aligned to the organisation's capability and strategy.

2.4.1. Flexibility in the Industry

Contemporary manufacturing companies have to strike a balance between changing customer demand, market share, and keeping fixed cost to a minimum. For many the answer is in technical innovation and advanced manufacturing technology. Although, we need to understand the core elements of the manufacturing process before appreciating the capabilities of advanced manufacturing. The core process includes: processing, assembly, material handling, inspection and test, Control and coordination. Most of these parameters are covered in detail in Section 5.2.

Manufacturing has been radically changed over the past decade because the relatively ‘static’ nature of market now has been replaced by high changeable market requirements. The new demand is hardly satisfied by the mass production, so new terms and requirements to manufacturing are fundamental. Crowson (2006) argues that most businesses get flexible primarily to reduce costs and thereby improve their competitive position in the market. However, the real objective of this investment is to make money by high volumes with reduced unit costs. The SOFC industry, because of its current low production quantities and low-rate production, has not been strongly influenced by high volume production concepts and automation requirements. Even though, automation can be justified due to precision requirement in assembling.

The UK industry prosperity depends on seven pillars of activities that the Department for Business Innovation and Skills have defined for firms to succeed. These are:

a) Macroeconomic stability,

b) Investment, science and innovation,

c) Best practice,

d) Skills and education,

e) Infrastructure and policies to ensure the right market framework.

In addition, infrastructure and policies to ensure the right market framework intends to highlight that any intention to implementation of new technology in the manufacturing process must warranty the market requirement. In the case of this thesis the market requirement will be basically defined by the projected demand by 2015. (Department for Business Innovation and Skills, 2006)

Shewchuk (1998) suggests three levels:

a) Strategic.

b) Operational.

c) Tactical.

Strategic-level decisions are concerned with what is to be made (product definitions), aggregate production volumes, and changing the manufacturing system at the facility level (e.g., buy or install new equipment, rearrange existing equipment). Tactical-level decisions are concerned with what product mix to employ, production rates to use, and the manufacturing system required. Operational-level decisions are concerned with the real-time operation of a given system configuration for specified production requirements, and changing the manufacturing system at the equipment level (Shewchuk, 1998).

Operational flexibility is used to achieve goals addressing:

a) Product quality.

b) Product costs.

c) Frequent introduction of new product designs.

d) Fluctuation in demand.

e) Processing of different product mixes.

Operational flexibility is achieved using a combination of machine, product, labour (i.e. the ease of increasing/reducing the workforce), material handling, routing, and volume flexibility.

Tactical flexibility is used to address issues such as:

a) Reduced product life cycles.

b) Variety of materials to be processed.

c) Inventory difficulties.

d) Uninterrupted operation for a long duration.

It is achieved using a combination of process, operations, program, and material handling flexibility (Boyle, 2006).

Sethi (1990) defines ten different types of flexibility, and the most influential for this dissertation is the machine flexibility and process flexibility. The machine flexibility is related to the various types of operations a machine can perform without changing machine. Process flexibility refers to the set of part types that the system can produce without any change over. These two aspects are essential to consider for the Thermiculite 866 because the intention to use the same production line for different variations of T866. In addition, the abrupt demand ramp up and product mix would require process flexibility. The flexibility requirement often requires flexible and modular equipments to obtain optimized layout.

Even though, Shewchuk (1998) argues that Flexibility is one of the most sought-after properties in modern manufacturing systems, but it is poorly understood in theory and poorly utilized in practice. One reason for this is the lack of general agreement on how to define flexibility: over 70 terms can be found in the literature. Even though they agree that it is not only an operational aspect but also an attribute of decision making, an economic indicator, and a strategic tool. Finally, it must be considered that increasing the potential flexibility to a point much greater than the required flexibility may result in an over-investment in manufacturing equipment. In addition, changing the potential and actual flexibility levels may also change organizational attributes and technological capability (Boyle, 2006).

2.5. Lean Manufacturing Implementation

Research by Barnes (2002) concludes that in Small and Medium Sized Enterprises (SMEs), realised manufacturing strategy seems more likely to be formed through a bottom-up emergent process than being derived, top-down, from business strategy. This fact might be important for Lean Manufacturing implementation especially because the intangible results of this approach are mostly seen on shop floor. In addition, as explained in Section 4.3, the project strategy needs to be implemented in hierarchical approach. Lean Manufacturing is a system of measures and methods which have the potential to bring a company competitive and waste reduction, not only in the manufacturing division, but throughout an organisation. In addition, Warnecke (1995) also went further to identify four individual aspects of Lean Manufacturing and classified them as: product development, chain of supply, shop floor management and after sales service.

Several authors claim there are three key aspects for Lean Manufacturing integration on. Communication - a vital tool for developing a knowledgeable and committed work force - provides a structured process for information flow within and between all levels of the organisation. However, for communication to work effectively a committed atmosphere needs to be fostered by acknowledging and appreciating workers behaviours, and also through frequent and sincere recognition, that creates a work environment which promotes loyalty, belonging, confidence, self-worth, teamwork, respect and creativity. Workers also need information to understand business strategies, perform a quality job, achieve customer satisfaction and contribute to performance improvement and ultimate success of the organisation (Lynch, 2006).

The recognition of employee involvement as natural process that needs to be nurtured and developed is predominately deficient in SMEs, consequentially creating and maintaining an environment that is receptive to lean initiatives is often difficult. With employee involvement being a key driver of other elements of Lean Manufacturing implementation, and especially in SMEs environment where special cause of variation are dominated by the need for extensive education and training that require periodic assessment for effectiveness, world-class practise tends to fail prematurely. However, exploiting an integrated manufacturing strategy that encompass a rational-linear and systematic-multiple-variant change management perspective for Lean Manufacturing implementation offer SMEs potential for sustainability (Esan et al 2007).

2.5.1. Lean Philosophy and Line Implementation

Considering the soft issues involved in Lean Manufacturing implementation included in the previous section, this section covers the practical way and methodology to implement Lean Manufacturing. Suzaki (1987) suggested that in factories, usually 95% of the total processing time is not being utilized to add value to the product. In fact, most of the time the material is waiting in storages between processes like the Thermiculite 866 raw material being storage in the warehouse for months. Furthermore, Suzaki (1987) suggested that Lean implementation requires 90% common sense and follow a simple sequence of activities: simplify, combine and eliminate.

- *First, simplify* the process by defining ‘the pitch’ and number of changeovers required to meet customer’s requirement.

- *Second, combine* all processes that can be performed by one operator considering the real process time.

- *Third, eliminate by* pull strategies.

In contrast, Alavi (2003) supports the statement of Dennis (2005) who argues that there is no roadmap for achieving a kaizen or Lean culture, and suggest leaving each organization to their own devices and methods. This strong argument suggests conducting the dissertation in the most convenient approach by considering the Flexitallic approach for planning and implementation of Lean in the future Thermiculite 866 line.

2.5.2. Team Work and Stakeholders Importance

According to the structured statement in Section 2.2, it is clear that the message from stakeholders must be synthesized from a broad vision into specific objectives. Each stakeholder would have different expectations that should be converted into common purposes. On the other hand, there would be always a different interest that may produce conflict between stakeholders. For this reason, according to Lynch (2006) it is a key issue to take them into account in the formulation of company’s vision and strategic decisions. The scope and frame of these decisions generates specific paths most times shaped by stakeholders’ role in the organization. For example, high managers may promote company profitability over other company achievements.

The best way to meet stakeholder’s expectations and promote change in the organization is by performing a stakeholder power study:

a) Identify the major stakeholders groups.

b) Establish their interests and claims on the organisation.

c) Determine the degree of power that each group holds.

d) Development of mission, objectives and strategy, possibly prioritised to minimise power clashes.

e) Consider how to reduce clash before it start by negotiating with key groups.

f) Identify the sanctions available and, if necessary, apply them to ensure that the purpose is formulated and any compromise reached.

(Lynch, 2006)

Finally, many companies set targets every six months. However, for an effective Lean conversion a more realistic conversion is 3 to 5 years with staged targets every 6 months or 12 months. Again, the initial iteration of staged targets may not be optimum but they will be a ‘start’, which can be annually adjusted. The targets set a board direction for the company over the next 3 years. The organisations need to work out how to achieve them by understanding their key business processes. Although other things can cause an impact and change within the trial period the goal of the organisation is to establish a baseline for effective Lean Manufacturing implementation as a manufacturing strategy.

2.6. Quality Systems and Product Development Management

As mentioned in Section 2.3 Quality Control in Thermiculite 866 line must be highly influenced by structured product/process development techniques. For this reason, this thesis intends to identify the best utilization of the QFD as an important section of TQM in this project.

2.6.1. Total Quality Management in Product Development and Plant Planning

The reputation attached to an organization for the quality of its product and services is accepted as a key to its success and the future of their employees. TQM is way of managing to improve the effectiveness, flexibility and competitiveness of a business as a whole. It involves the whole company getting organized in each department, for each activity and each person, at each level. There are three major components of TQM proposed by: (Muhlemann, Oakland, & Lockyer, 1992).

a) Documented Quality Management System

b) Statistical Process Control (SPC)

c) Teamwork for Quality Improvement

Process control is a function in a production process that seeks to find deviations from the optimum process outputs and also uses proactive means to look for any process shifts before the product quality is compromised as it will be demonstrated in the mixing and spreading development (Sections 5.7 and 5.8). Many well-documented techniques are used in this endeavour – the most obvious is the use of SPC. In a simple manufacturing process, the use of SPC will entail the use of control charts where the output of a given process is measured and charted. Dr Walter A. Shewart (1891-1967) is credited for the development of the control chart, where the upper and lower limits are set at ±3 times the standard deviation, based on normal variation. When the process produces results outside these limits, it is said to be out of control (Goh, 2002).

Although, there are major considerations before SPC and other QA techniques can be implemented on the shop floor. One of them is QFD, which has gained prominence since Mizuno and Akao published their first book on the topic in 1978. The modified QFD approach integrates product and process development (IPPD) as an extension of concurrent engineering in the design of the Thermiculite 866 high volume production line. The main QFD method was not modified, and it has been proposed the use of a systematic way to conduct integrated product and process development. The proposed QFD approach is driven by business priorities and adapts the differences in applications resulted from changes in product development as will be explained in Chapter 3.

The term QFD refers to the concept and methodology of NPD under the umbrella of TQM. The QFD is a methodology for transforming the customer's requirements into product characteristics and further more into process and production characteristics. QFD uses four "houses" to integrate the information and requirements of marketing, engineering R&D and manufacturing. According to the first traditional scheme published by Mizuno and Akao (1978); there are four houses: HoQ, parts deployment, process planning and process and quality control (Akao, 1990). Shiu (2007) claims that QFD practitioners posses several misperceptions about the "QFD essence". The common misunderstandings include the utilization of the Quality Deployment equivalent to "quality chart;" and QFD being equivalent to quality deployment. Pinto and Kharbanda (1998) identified other major causes of NPD failures such as ignoring the project environment, stakeholders' requirements and project objectives.

The broad concept of quality and its philosophy provides few possibilities to alter the basic QFD concept and redefine a new QFD approach to achieve an optimal product development. The structural change of the “four houses” has produced different approaches and new variables into the practice of QFD for product development. For example, the Matrix of Matrices Model deals with:

a) Quality

b) Technology

c) Reliability

d) Cost

In addition, to the popular QFD Four Matrices. This modified QFD approach aims to extract any bottleneck-technology, to prevent potential failures and to achieve target cost. The development of QFD has demonstrated that modern product development requires more accurate market analysis and business integration, although, this continuous sophistication of the QFD has brought other issues regarding information management.

2.6.2. Further Development in Quality Function Deployment

Several problems can be encountered during the implementation of sophisticated QFD. For example, erroneous conclusions can be magnified by serial processing. Therefore errors introduced at one stage will propagate to the entire analysis. In addition, Bruce (2001) argues that the QFD complexity may be a time-consuming process requiring a lot of detail. In fact, 30 customer requirements and 50 design requirements lead to 1,500 different links to be discussed. This is a real issue for QFD practitioners considering that a typical application can have 30 to 200 requirements (Hauser & Clausing, 1988).

The QFD literature has demonstrated that there is significant complexity in the use of rating scales to prioritize the QFD final outcome (Franceschini & Rupil, 1999). Furthermore most QFD researches have focused on the scoring mechanism.

Ten percent of the QFD practitioners use the four-matrix model; another 10% use the Matrix of Matrices approach exclusively. Finally, the remaining 80% use an integrated approach combining the best features of both models. This clear message defines the importance of “customized” QFD in order to achieve practicality in the industry. For example, Marsh (1991) integrated a model based on Deming’s Plan, Do, Check and Act (PDCA) cycle in order to link QFD with Lean Manufacturing philosophy. In fact, this seems to be the start of more customized approaches. Ten years after the first QFD publication, some practitioners intended to link QFD to technology, cost and reliability in NPD cycle Shiu (2007). Furthermore, Zultner, a student of Akao, designed a streamlined approach called “Blitz QFD” that intended to select and deploy only the top most influential customer needs (ReVelle, Moran, & Cox, 1998).

Sullivan (1986) and Clausing (2006) were important figures in the initial development of QFD in the industrialized western countries. Afterwards, QFD was gradually introduced to researchers and practitioners in different of manufacturing fields. Then, QFD was combined with various design methodologies and numerical analysis methods that promoted more research afterward. Jiang (2007) defined three main aspects that have been explored:

a) QFD combined with (theory of inventive problem solving) TRIZ,

b) Taguchi methods in order to improve its effectiveness QFD as part of product design and process design

c) QFD combined with numerical methods in order to strength the accuracy of the analysis

2.7. Commercial Awareness as a Mechanism of Knowledge Incorporation in QFD

The levels of TQM and International Organization for Standardization 9000 (ISO9000) development define the major quality methodologies in organizations. Historically most of the organizations in Europe were more exposed to ISO9000. Although, there are several important reasons to promote TQM in these companies. Planning and QFD intends to improve NPD and reduce delays in projects. This thesis proposes a renewed approach to use the original QFD and integrated organization objectives during product development.

As mentioned in the introduction of this study, “Novel-QFD” provides several reasons to promote flexibility and customization to the original QFD. In fact, there are several aspects to be covered in QFD. For example, cost and product life cycle are important inputs to be incorporated in the analysis. Several authors have assertively implemented more sophisticated QFD scoring mechanisms. Although, these approaches constrain the QFD due to excessive time required for its implementation. Moreover, the proposed QFD must promote communication to improve product development and Lean implementation. Successful companies optimize product life-cycle designs by employing well-organized design reviews and utilizing the culturally inherent communication between designers and engineers responsible for production and maintenance.

The aim to envisage the process prior to QFD has been a common point of view among QFD practitioners. Bruce (2001) proposes a hierarchical framework to improve the effectiveness of decision making. This hierarchical framework suggests six stages before starting the HoQ:

a) Voice of the Customer.
b) Competitive Analysis.
c) The voice of the Organization.
d) Design Targets.
e) Relationship Matrix.
f) Correlation Matrix.

In fact, the initial forced priorities often depend on product positioning in the market and the life cycle. For example, QFD initial priorities should be affected by the role of product features, cost, and time to market. Chao (2004) proposes a matrix that begins by identifying constrained factor (e.g. hard limit on time-to-market, hard budget/cost target, a new level of features/functions). Second, the priority to be optimized needs to be defined (e.g. quicker time-to-market, minimize cost, maximize features). Furthermore, Sarbacker (2009) identified the importance of risk assessment in three main aspects: envisioning risk, design risk and execution risk.

Lu & Kuei (1995) suggest that the application of QFD in the strategic planning process could be applied for corporate departments such as marketing, finance, accounting, R&D, etc. (Lu & Kuei, 1995). This view incorporates corporate strategy into the process to decide about products, processes and operations, and suggest continuous reviews of customer strategy. In addition, Killen (2005) suggest that QFD-based methods should start with customer and stakeholder outcomes. Finally, the inherent culture of the company is an important driving force for the application of QFD. For example, in companies that emphasize NPD, the 'forced product features' involve the setting of product specifications. Early stages of the QFD begin with demanding quality deployment, and determine critical quality characteristics and design for quality. On the other hand, in companies that emphasize manufacturing, the QFD activities begin with acceptance of product specifications. This should be followed by demanding quality deployment and quality planning before the setting of product specifications.

2.8. Facility Planning Project for High Volume Production Systems

Considering this thesis covers the design of a high volume production line, the future demand and its implications are crucial for the production line design. The analysis conducted needs to define a good alternative to plan and design a high volume production line.

Deleryd (1999) identifies that manufacturing companies need to make decisions and improve their processes based on accurate and timely information relating to the performance of their manufacturing process. It, therefore, follows that the development of process control theory, experimental design concepts and issues relating to product reliability cannot solely remain in the domain of the larger industries. In fact, lots of efforts at Flexitallic have been focussed on the application of such principles and continue training and development of the company's workforce. Some of the greatest benefits of Lean Manufacturing Systems, such as labour cost reduction and stock level reduction, can be quantified using traditional cost accounting techniques. However, from the mid 1980s onwards, leading engineering, accounting and management journals in the UK and USA the relevance of such techniques became increasingly critical. Indeed techniques such as the ‘payback period’ and ‘return investment’ criteria were variously described as ‘a primary obstacle to companies’ adoption of Continuous Improvement Management

(CIM) (Clark, 1995). For this reason in the following sections no economical analysis has been considered and only related aspects such as manpower and hours per units produced are part of the analysis.

Considering the area that will be used to implement the Thermiculite 866 line as a “Greenfield” site, is not difficult to decide and adopt two principles which dominate the modern factory literature: zonal layout and modular design (Clark, 1995). The zonal principle involves laying out the production process sequentially to bring together all the machines in each area or zone of production. Finally, modular design is hearth of the Thermiculite 866 considering the abrupt increase of demand in the next five years.

2.9. The Product/Volume-Layout/Flow Matrix

The definition of the matrix is the result of an extension of the process matrix developed by Hayes (1979) because they found that many factory characteristics vary in accordance with these two dimensions: product structure and process structure. Miltenburg (2005) suggest that the definition of the first dimension: Production and volumes is easy to define. Figure 2.2 shows the layout and material flow vs. products and volumes.

The definition can be subjective and not precise because it is based in a general appreciation because there is not any particular evaluation to define this dimension. The definition of the layout is easier due to it is linked to the material flow and process flow. In fact, material flow depends on the layout, but for a particular layout can vary according to the operation.

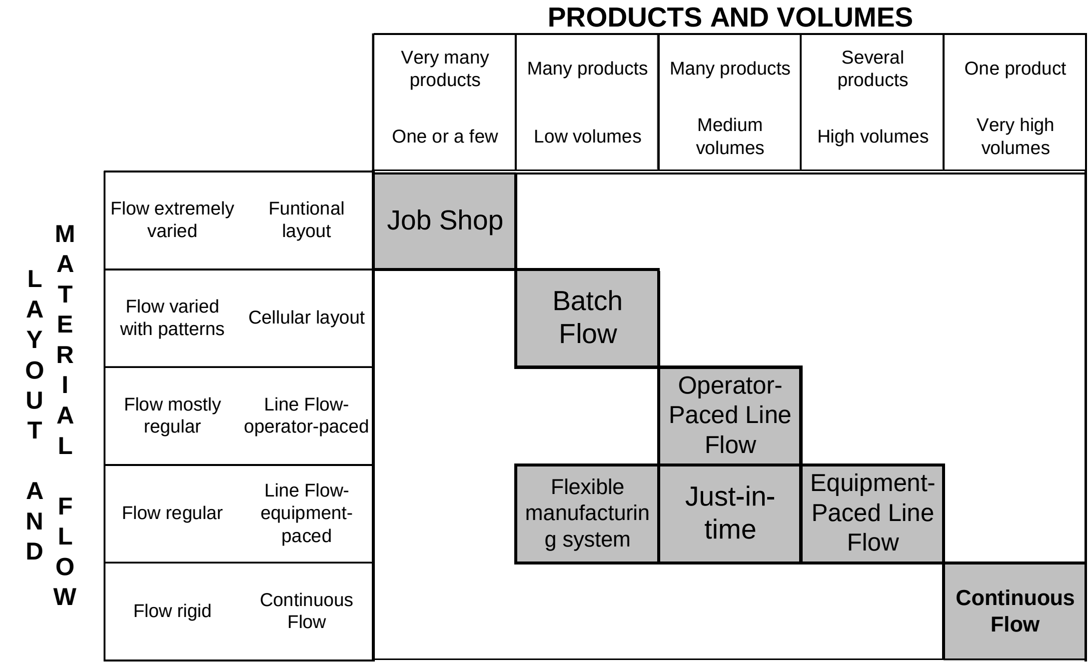


Figure 2.2: Product/Volume-Layout/Flow Matrix

Source: Adapted from (Miltenburg, 2005)

The different characteristics of the production systems are:

- JOB SHOP: Produces a large number of different products in low volumes in a functional layout. The equipment is located according to the machine purpose, and it is required of highly skilled operators. Usually there are high work-in-process inventory and long waiting times.

- BATCH FLOW: Produces few products in batch basis that usually represent a period of time demand. A combination of functional and cellular layout is used. In this system the material flow varies from order to order, although there are patterns of flow for most common families of products.

- LINE FLOW EQUIPMENT-PACED: Produce a small number of product families in high volumes. The product is capital intensive and specialized. Operators perform relatively simple tasks at a rate determined by the line speed. Some examples of this system is adopted by some luxury carmakers.

- LINE FLOW OPERATOR-PACED: The system has lower capacity and more flexible approach compared to an equipment-paced. Actually, compared to a JIT system the capacity of variation in production mix is almost the same. The operator-paced line speed depends on the number of operators assigned to the station on the line, the speed at which operators work individually and as a team. Material is regular for most of the production, and equipment is flexible to support changes in production. This system provides good level of all manufacturing outputs when the number of products is high and the production volume is low. McDonald's restaurants runs one of the best-known operator-paced line flow system because of the capacity of manage the demand change during the day in different products.

- CONTINOUS FLOW: Resembles the equipment-paced line flow production system, but it is more automated, specialized, capital intensive and less flexible. It has almost no operator assistance for the 24 hours production. The system produces a product with the highest possible quality and lowest possible costs.

- JUST-IN-TIME: It is a line flow production system that produces low to medium volumes of high mix of products, and it is involved in a continued improvement process to reduce waste all the time.

- FLEXIBLE MANUFACTURING SYSTEM: FMS consist of computer-controlled machines, an automatic material handling system and a computer system to produce many different products in low volumes. For example, a Pratt and Whitney FMS in Canada produces 70 different products for the aerospace industry in volumes ranging from 30 to 1000 units per year per product.

The Figure 2.3 shows manufacturing outputs by including a scale of numbers from 1 to 10. The qualification of 10 represents Good and 1 represents poor output.

PRODUCTION SYSTEM	MANUFACTURING OUTPUTS					
	Delivery	Cost	Quality	Performance	Flexibility	Innovativeness
Job Shop	4	1	2	1	10	10
Batch Flow	3	3	4	5	8	8
Operator-Paced Line Flow	4	4	5	7	4	5
Line Flow-equipment-paced	5	8	8	5	2	2
Continuous Flow	5	10	10	1	1	1
Just-in-time	6	7	7	5	5	5
Flexible manufacturing system	4	6	6	5	5	3

Figure 2.3: Manufacturing Outputs

Source: Adapted from (Miltenburg, 2005)

Miltenburg (2005) claims that flow lines provide better levels of cost and quality compared to systems such as Job Shop and Batch Flow. Continuing with the Chart 02 output analysis, the production systems near the top of the manufacturing chart are able to provide better levels of flexibility and innovativeness than production systems such as flow lines. Finally, the best performance can be found in systems that are not excessively machine dedicated or people oriented. Well managed production systems based equally on the capabilities of machines and people, can best provide a high level of performance year after year Miltenburg (2005).

2.10. Fundamental Principles of Systems Engineering

Mathaisel suggests that there are five fundamental tasks that should be followed the definition of the requirements of the company in order to design a new facility:

a) Conceptual design: Product analysis, production volume, job shop, trade-off analysis, make-buy, benchmarking and Lean Principles.

b) Preliminary Design: Ideal functional layout, rough scale simulation, human resource planning, production sequence, facility planning, cellular design and Lean principles.

c) Detailed design: Equipment design, flow analysis, simulation, detailed floor layout, work organization, benchmarking and Lean Principles implementation considerations.

d) Implementation: equipment selection, quick setup time, installing equipment, training, testing, adjusting, benchmarking and Lean practices.

e) Operation: leadership, innovation, monitoring, planning & control, continuous improvement, stabilization, engineering change management and best Lean/cellular practices (Mathaisel, 2005)

2.11. Macro Space Planning Model

The facility layout is the arrangement of activities, features and spaces in consideration of the relationship that exists between them. Facility or plant layout is a part of facilities design that includes more global issues such as plant location, building design, material handling, etc. In general, plant layout analysis includes a study of the production line flow charts, material flow diagrams, product routings, relationship diagrams between different departments in the facility and the cost of material movement (Hales, 1984). The process suggested by Lee in Tompkins (2003) is to define the following steps as part of the information, strategy and layout stages:

- Information: Plan project, analyse products and volumes, analyse current process.

- Strategy: Develop operational strategy and business architecture, define space planning units.

- Layout: Analyse material flow, no-flow affinities, calculate space, identify constrains.

In addition to the methodology suggested by the author is important to mention some considerations by Harmon and Peterson in Tompkins (2003) to obtain a flexible layout:

a) Provide maximum perimeter access for receiving and shipping materials to shop stations.

b) Minimize the workstations size to avoid time waste and motion of workers.

c) Eliminate centralized storage and move storage where required.

d) Minimize the amount of factory reorganization in case of future growth.

2.12. Future Production Line Efficiency and Design Effectiveness

Stewart (2004) claims that companies generally try to settle into more stable ways of working such as more fixed working patterns. For example, the static product line like the current Thermiculite 835 line has been a reference for product development at Flexitallic. He suggests that the best companies make it easy to figure out the organization's structure as well as its process/flow of work through production systems that give inertia to the operation. This argument suggests that these organizations are always clear, visible to employees for quicker track of difficulties. Finally, visual business processes allow everyone in the organization at all levels to understand specific roles in the company and in what form their contribution has helped to the company's revenue. In other words, a flow line should be prioritised into the design process of the Thermiculite 866 as it will be mentioned in the Section 3.8 with the flow/batch matrix.

Finally, the day-to-day control of the production line should be measured. Line and project performance is usually defined as meeting time, cost and quality objectives and satisfying project stakeholders (Baccarini, 1999). This may be refined into achieving product success such as product standards or process success such as volumes of production. These performance measures are according to the client requirements, stakeholders objectives: own proposal for the Thermiculite 866 line, cost and specifications. In fact, most of the critical selection and commissioning of contractors were according to internal Flexitallic criteria. More than two hundred tasks were defined in Appendix 3 to monitor performance and gates in the project. The performance needs to be communicated in monthly meetings to the project board.

Structured management is required for continuous improvement and operation of the line when Thermiculite 866 has reached the forecasted demand in 2015. Hill (1987) suggested structural and infrastructural issues as two pillars of manufacturing strategy. Structural issues set the process and technology for operations whereas infrastructure provides it with long-term competitive edge by continuously improving upon human resource policies, quality systems, organisational culture and information technology. Infrastructural issues are long-term goals and supports to the structural issues that mostly would be covered during the implementation stage. Furthermore, infrastructural issues are developed through persistent day-to-day use and with commitment of top management and teamwork at all levels. These are intangible and developed over a certain period of time with consistent use and polishing. Effective use of infrastructural issues with structural issues leads a firm towards manufacturing excellence (Hill, 1987).

2.13. Introducing an Innovative Approach for Plant Design and Introduction to a Novel QFD

The Thermiculite 866 project offers chances to develop and purpose methodologies for plant design and product development. The author has presented and published two papers in the 26th International Conference of CAD/CAM, Robotics & Factories of the Future on 26-28 July 2011, Kuala Lumpur, Malaysia. One of the papers, titled The SAQFD as a key driver for the design of a high volume production line is attached to this thesis in Appendix 1. This is the first attempt to define a methodology to run and implement a SAQFD as part of the Thermiculite 866 project. In addition, Appendix 2 includes the second paper which is an innovative methodology for designing a production line. This paper covers the called batch/flow comparative matrix for the plant and lay out design.

2.14. Chapter Summary

This literature review chapter establishes a solid theoretical base for the definition of management strategy to promote continuous evolution in the operational system by promoting change in organisation culture. The role of the KTP project has been covered according to the required commitment of senior managers and employees.

This chapter covers the first intent to enclose the plan and strategy to implement concepts of flexibility, Lean Manufacturing and tactical flexibility. The concept of QFD is introduced and described as fundamental and a flexible tool in TQM and product development. Pinto and Kharbanda (1998) evaluate the QFD version from 1978 and suggest the requirement to introduce project objectives. The sophistication of the classic QFD has produced changes in layout such as the Matrix of Matrices Model. Although, Hauser (1998) proved that practitioners require simplicity in QFD approach. This chapter includes Jiang's (2007) synthesis of main fields that have been incorporated into QFD. The author would like to highlight: QFD combined with TRIZ. The importance of this proposal is the implementation of a structured decision making technique into QFD. Furthermore, Bruce (2001) suggests a hierarchical framework to improve QFD along to project definition. Finally, Lu&Kuci (1995) suggest more encouraging approaches to use QFD in department such as Finances or Accountant. This Chapter concludes that business priorities and the environment of the project are stated as important mechanisms of knowledge incorporation and modification of the original QFD.

Furthermore, a proposed Batch/Flow Comparative Matrix is developed from the plant design methodologies discussed in Chapter 2. Finally, Chapter 3 includes the adopted strategy to manage and support change in product development and production management.

CHAPTER 3

RESEARCH APPROACH AND HYPOTHESIS DEVELOPMENT

3.1. Introduction and Background

The extension and scope of the classical QFD for product development requires an extensive workforce for product development which is infeasible in most SMEs. Furthermore, project managing and plant design increase complexity and resource requirements to the whole product development cycle. The main QFD method needs modifications in order to provide a systematic way to conduct integrated product and process development. Finally, the new conceived QFD needs to be driven by business priorities and adapts the differences in applications derivate from changes during development and implementation. The novel QFD scheme needs to be part of a bigger picture of project planning and implementation of the future Thermiculite line. For this reason, the proposed methodology needs to consider incorporating the new QFD as part of a structured planning that includes process design and equipment implementation. This last requirement is fundamental to accomplish a complete emersion of the QFD in the design and implementation of a production system. Furthermore, it is required to intensify the importance of management through the project implementation by securing a clear organizational structure prior the QFD.

This statement provide high quality standards, better services and potentially a way to master the complexity involved in using for example QFD and Project Management separately.

3.2. Theory Building for QFD Development

This thesis aims to research literature and develop a new methodology to improve the QFD approach whilst the implementation of a high volume production line, and following the statement that summarize this goal:

"Develop a novel QFD method and management methodology to support the management in the design and implementation of a high volume production line"

This statement above and the following assumptions will define the frame to be analysed in the research methodology. The group of assumptions for the theory building are:

- It has been a priority for this project to assembly of different aspects of product development as possible in the organization to promote concurrent engineering. The author decided to merge QFD in project planning and plan design.
- SMEs require flexibility to implement TQM and project management techniques during product development and research. The new QFD requires flexibility regarding of definition of requirements from stakeholders as key interactions with the product development.
- The new development approach needs to provide a simplified approach while securing the concept of QFD is maintained. In fact, the use of QFD needs to be common for product launches which will improve the organization competitiveness.
- The proposed QFD and its project management need to be repeatable for different products and in different conditions.

- Finally, the development or proposal needs to be part of the company's capabilities in order to produce a real impact in the organization by producing a holistic approach during product development.

3.3. Research Objectives and Evaluation Strategy

The research objectives refer to the objectives to develop a new theory in order to improve the utilization of QFD during product development:

1) Identify the limitation of classical QFD to produce a base for a QFD development.

2) Develop a methodology to produce a Strategically Aligned Quality Function Deployment (SAQFD) and the supporting management approach to support the product and process development.

3) The benefits need to be assessed comparing classic QFD and SAQFD from a theoretical point of view. In addition, the Thermiculite 866 which is the research case provides an evaluation of the proposed QFD and management scheme.

3.4. Research Methodology

After a general framework of the project intension, it is important to define the initial research question behind the proposed study (Voss, Tsikriktsis, & Frohlich, 2002). The proposed questions to cover 'what is' are:

- What changes require the QFD to support product improvement in SMEs?

- Which mechanism can be used to introduce a QFD practice in planning and company's vision and strategy?

This thesis proposes a theory building based on a descriptive research from the literature review. Furthermore, an experimental research that compromise the implementation of the proposed QFD in the Thermiculite project. This single case study is a good opportunity for an in-depth study in longitudinal manner as suggested by Voss (2002). This longitudinal case study is an on-going project expected to be signed off by 2016. For this reasons, the research would be affected by generalization and lack of effect in Flexitallic. On the other hand, these unwanted effects will be reduced by clear assumptions and extrapolation of the current achievements. In fact, the analysis will be constructed from present information in order to draw valid conclusions at the end of the thesis. It is important to mention that this is not a theory built from a case research. In fact, the SAQFD and the Batch / Flow Comparative Matrix are based on rationalism of the literature review.

The developing of this theory will be based on process simplification as a driver to reduce time to market while considering the company's strategy and vision. In order to cope with this objective the research activities:

- Literature Review for theory building in QFD and plant design. This will be supported by a case study that will show the project management and proposed novel QFD.
- The evaluation will be conducted considering assumptions and success factors.
- The descriptive research developed in the next section introduces two major academic deliveries considering the research questions:
- To define a product/process design methodology to involve company's stakeholders while securing quality assurance during product development.

- To define a planning framework and all supportive methodologies to introduce a novel QFD in product development and plant design.

The proposed scheme provides a shorter and leaner product development to market in SMEs. This is possible because SAQFD incorporates business requirements and objectives straight in to product, process and production prior the QFD exercise. The objective explained in Section 1.7.2 would be evaluated considering the applicability of the SAQFD scheme and the results during the implementation in the Case Research (Thermiculite 866 project).

3.5. Theory Building: The Strategic Alignment of Quality Function Deployment

As explained in Sections 2.6, the original QFD supports modification. This study proposes a Novel-QFD defined by forcing some of the product features and process requirements prior to starting the first HoQ. The application of "inherent" commercial strategies leads to define the optimal process specifications for specific components. This thesis intends to prioritize stakeholders' requirements and commercial awareness as a key factor to define QFD requirements at SMEs.

QFD has been conceptualized for the product design stage that is just at the beginning of the product life cycle. The redesign or improvement of products is not clearly supported by the original QFD approach. In contrast, most of the SMEs mostly improve their products at later stages as product reach its growth stage. Furthermore, many firms do not have mechanisms in place to formulate and clearly support product growth while implementing QA in their sites. This thesis proposes a QFD approach based on cascade of organizational objectives. In addition, this basic frame needs to be populated by the best ideas coming from whole organization to improve aspects such as productivity and quality. Ideally the requirements should be phrased towards non-engineers, like accountants or lawyers, in a qualitative manner in order to bring a broader solution. Finally, as suggested by Husband (1997) in Section 2.3 and considering the usual limitations of SMEs, this thesis needs to propose a methodical analysis of strategy prior start the full QFD. In the following paragraphs, the author explains the mechanisms to modify the original QFD in order to provide a strategic approach in product development at any product life stage. This approach has been called as a SAQFD.

The mechanism of the SAQFD implementation needs to be implemented in tactical level and operational level as suggested by Shewchuk, (1998) in Section 2.4.1. For this reason, as suggested by Bruce (2001), the author of this thesis adopts a hierarchical framework to improve the effectiveness of decision making during the SAQFD exercise. The two priorities to be considered are cost and time to market as suggested in Section 2.7. Finally, it is important the suggestion from Killen (2005) that suggests that QFD-based methods should start with customer and stakeholder outcomes.

The concepts previously explained are applicable to every organization. Even though, there are strategies and workforce alignments particular to SME. Lu & Kuei (1995) suggest that every department in the organization should be involved in the assessment of the QFD, and the author suggest that this should be performed prior starting SAQFD. Furthermore, SAQFD proposes to introduce SMEs way of doing things as suggested by Killen (2005) from the start. Company situation defines restrictions in economic stability, investment in the project, staff skills and education, infrastructure and inherent policies have an important impact in the approach to the NPD.

The SAQFD propose two fundamental conjunctions to link the marketing plan and the corporate strategy to QFD. This key grouping is workforce and strategic alignment, displayed in Figure 3.1.

The SAQFD can be represented by two main “streams” of influence and information:

- Workforce Alignment.
- Strategic Alignment.

Both of these sources of forced requirements will define a Novel-QFD shaped by organizational mission & vision through corporate strategy, and the introduction of specific requirement is represented by the arrows in Figure 3.1. For example, the number one in the square represents an early forced requirement in the process for one specific team involved in the QFD. The specific requirement may be the use of Design for Manufacturing (DFM) to modify product features instead of filling a gap such as low-skilled manpower or technological limitations.

This demonstrates how a specific solution is dragged into product redesign instead of influencing the process redefinition to accomplish customer requirements. This downstream feedback might be considered an atypical modification of the QFD, although this approach is fully compatible with the newer Concurrent Engineering practices mentioned above in product development. In fact, SAQFD provides a structured development process for companies that need to include their limitations in NPD. The major difference with the original QFD developed by Akao is the importance that SAQFD gives to business awareness and the relative flexibility required during the HoQ development. This means that Operations needs to interact closely with Designers to define some parameters that would be reflected in the product.

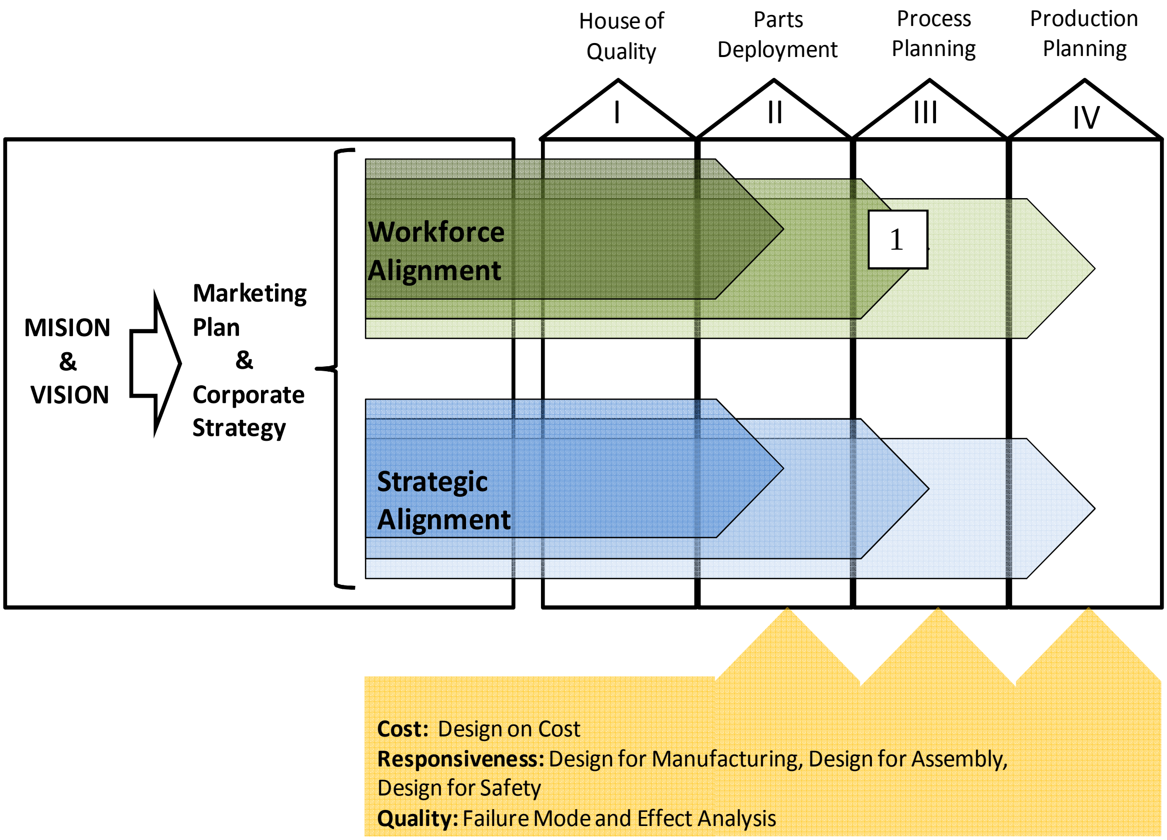


Figure 3.1: The Strategic Alignment of QFD

SAQFD requires specialized support analysis in three major fields: cost, responsiveness and quality to support any forced requirement in House I, II, III or IV. The chart in the bottom of the graph represents the set of product development techniques to facilitate the introduction of any feedback or loop to HoQ. In this part, the TQM on SPC and documented quality management system provides base to support any stage in the QFD: HoQ, parts deployment, process planning and production planning. In addition, Lean Manufacturing tools offer more support to the process.

Second, the Workforce Alignment or Organizational Alignment, which might part of a greater Human Resource study, is partially covered in this thesis. Each department in the organization needs to understand their specific role and responsibility of specific stages in the project. The communication between departments and the ability to identify some of the requirement in the different QFD houses will define the success of the NPD. Ideally, the SAQFD should start by involving people from different levels in implementing and thinking about company practices. Provide feedback to management and engineers on cost-effectiveness and project specific aims. It is important to use factual information about what is happening based on unbiased objectives with informed staff. Are the company vision and mission aligned? Major requirements should sound like solutions but avoiding the high-level project goals and challenges, like “make cheaply”, “produce better quality”, and “meet new demand”. The flow of information and involvement of the team is a key factor for defining successfully the Strategic Alignment.

The Strategic Alignment adapts the original QFD to the business perspective requirements in order to effectively implement process planning and production planning. A well-informed team promotes ideas from different hierarchical levels which produces valid forced relationships. The business and company philosophy defines the major project drivers. For example, a company that prioritizes manufacturing above other departments might promote production capacity and capability as part of the Strategic Alignment. The Workforce would be aligned under a manufacturing leader that would manage the project to fulfil operations requirements.

A successful Strategic Alignment produces a detailed project plan with tasks according to a specific timescale. The SAQFD will define the structure of this plan based on the four QFD Houses:

1) Engineering characteristics (HoQ)

2) Parts characteristics

3) Key operations process

4) Production requirements

This structure is based on fundamental principle of system engineering which suggests starting with conceptual design and continues with detailed design. The mechanism to define each section will be based on the PDCA Deming's Cycle, and supported by facility planning project and design. In this stage, the SAQFD would produce a detailed project plan and all of its advantages. For example, it would lead to identifying a "critical path" and the necessary backup plans that can be addressed to accomplish a successful NPD. To conclude, the SAQFD provide an improved utilization of the original QFD approach by developing a strategic plan that consider the project environment such as company vision as is demonstrated in Section 5.3.

3.6. SAQFD Methodology and Application

As shown in Figure 3.1 the main aspects to consider are the alignment of the business and the workforce. The author of this thesis suggests picking specific approaches from the literature review that supports the proposed SAQFD. All methodologies in the following section support the SAQFD objectives

Workforce Alignment is achieved by defining stakeholders' priorities, team structure and master plan.

The stakeholders' priorities: Based on the stakeholder power study proposed by Lynch, (2006) in section 2.5.2, the author picked priorities to involve managers and directors to define main objectives and strategy.

Team Structure: The team structure must involve all the organisation and this might be demanding for SMEs considering their limited resources. Even though, they must warranty at least marketing - research - manufacturing link. Define roles and responsibilities linked to the QFD practice. For example, first two SAQFD stages: HoQ and Parts Deployment need to be conducted by R&D. The next two stages: process and production planning would be conducted by operations or manufacturing.

Master Plan: Each organization needs to define and plan at least a conceptual design, detailed design and implementation stage.

Strategic Alignment is achieved by analysing product, analysing current process, and conceptual design supported by Batch Flow Comparative Matrix.

Analysis of Product: this analysis covers aspects such as demand and facility type which have direct impact on the definition of predefined or forced requirements on process parameters in the manufacturing planning (third house). These changes will eventually affect the last matrix: production planning.

Analysis of Current Process: This analysis is more likely to be required for process improvement and it covers aspects such value stream mapping which affects the process planning (third house).

Conceptual Design: This should cover cycle time, layout analysis, and information and material flow. This analysis defines fixed conditions for production planning (fourth house). This section will be highly supported by a proposed decision support matrix the author has called the Batch / Flow Comparative Matrix in Section 3.8.

As shown above "forced requirements" would affect specific houses in the QFD and will transform the approach to the SAQFD. Finally, the series of four houses format proposed in the original QFD might be transformed to consecutive "hows" instead of translating them to consecutive houses. Figure 3.2 displays this concept that will be fully explained in the Chapter 5 with the case research.

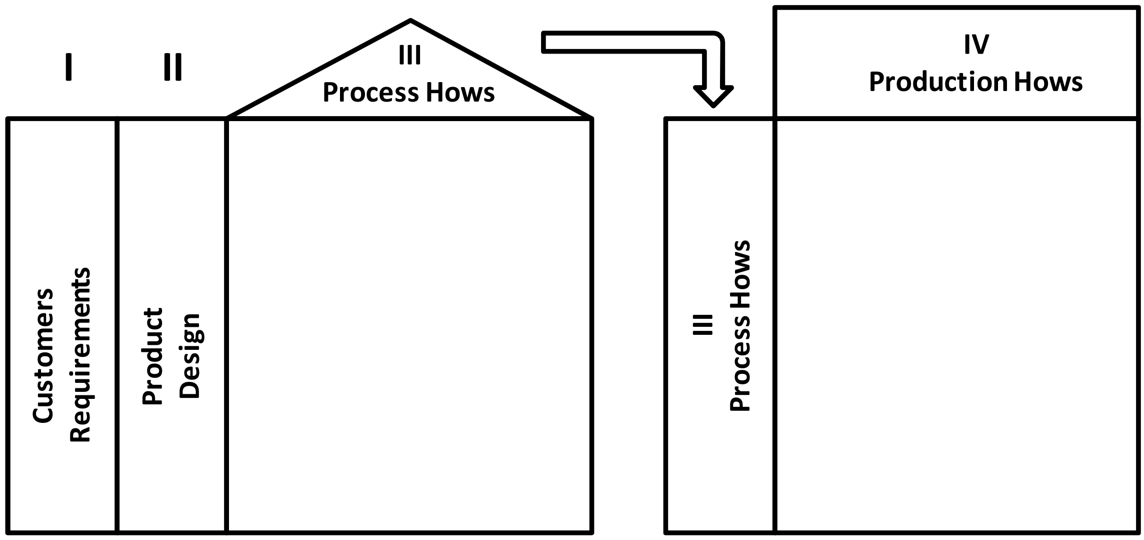


Figure 3.2: The SAQFD sample

This proposed layout was applied for the Thermiculite 866 project and it has been included in Figure 5.7 where customer requirements and product design are in the left hand side of the house.

3.7. Innovative Design Methodology and Project Planning for the High Volume Production Line Design

The different planning models and its similarities in terms of outputs and flexibility are displayed in the Figures 2.2 and 2.3. The different methodologies were detailed in the Literature Review, and this section will define the best design concept for the Thermiculite requirements. In order to define the new methodology model the following aspects must be included:

Three different approaches consider an initial definition based in the business requirements and company vision from SAQFD. For that reason, it was defined the first common stage for the future project methodology. In fact, there are two main reasons to use a specific manufacturing system. First, consider the mix and volume required to accomplish the demand. Second, recognize the output required in terms of cost, quality, performance, delivery, flexibility and innovation.

This thesis intends to combine analysis of demand, facility design methods and project management techniques to develop the conceptual design of a high volume production line. Heaton (2003) suggest that the design must consider the following strategies: Take into account customer requirements, take into account competitors, take into account manufacturing capabilities, consider all options available to manufacturing, list of the required outputs that manufacturing will provide.

A more specific approach is suggested by Lee in Tompkins (2003), who defines the following steps as part of the information, strategy and layout definition:

- Strategy: Develop operational strategy and business architecture, define space planning units.
- Layout: Analyse material flow, calculate space, and identify constraints.
- Product Analysis and Current Process: Display the current state value stream and definition of product family (Tompkins J. , 2003).

In addition, Hales (1984) suggest a plant layout analysis that includes studying of:

a) Production line flow charts

b) Material flow diagrams,

c) Product routings,

d) Processing times,

e) Relationship diagrams between different departments in the facility

f) Cost of material movement

The reader must understand that the development of a new production line or layout must not include only a process design but also the management during implementation. For this reason, the proposed Conceptual Factory Planning Methodology needs a first stage of planning and a second stage of commercial awareness proposed by Heaton (2003). In addition, it must include material flow and layout analysis as suggested by Tompkins (2003) and Hales (1984). Furthermore, the characteristics and relationships defined in the SAQFD highlighted the necessity to incorporate a parallel Lean & quality development process in this project Yumbla et al (2011). Figure 3.3 displays the proposed model for high volume production line design and the required support from process development and equipment trials (grey flow line). This figure is the result of Heaton's planning suggestions and Tompkin's basics on layout analysis based on material flow. Each section of the project (blue boxes in Figure 3.3) is defined by subtasks grouped according to different phases described in Tompkins (2003) in Page 62 in this thesis. The implementation of this structured process warranties the success of the project and the best QA system and Lean implementation. In fact, the partition between conceptual design and detailed design represents the required Lean evaluation before continue with the future implementation. Furthermore, each specific task such as mapping the current process or design, detailed layouts is the result of a broad analysis based in PDCA continues improvement cycle. The tasks displayed in blue boxes on Figure 3.3 are supported by subtasks that cover details such as process time, equipment design and visual management on shop floor. Figure 3.3 is the displays the most suitable subtasks to design the future Thermiculite 866 line based on the literature review explained in section 2.3 and 2.4.

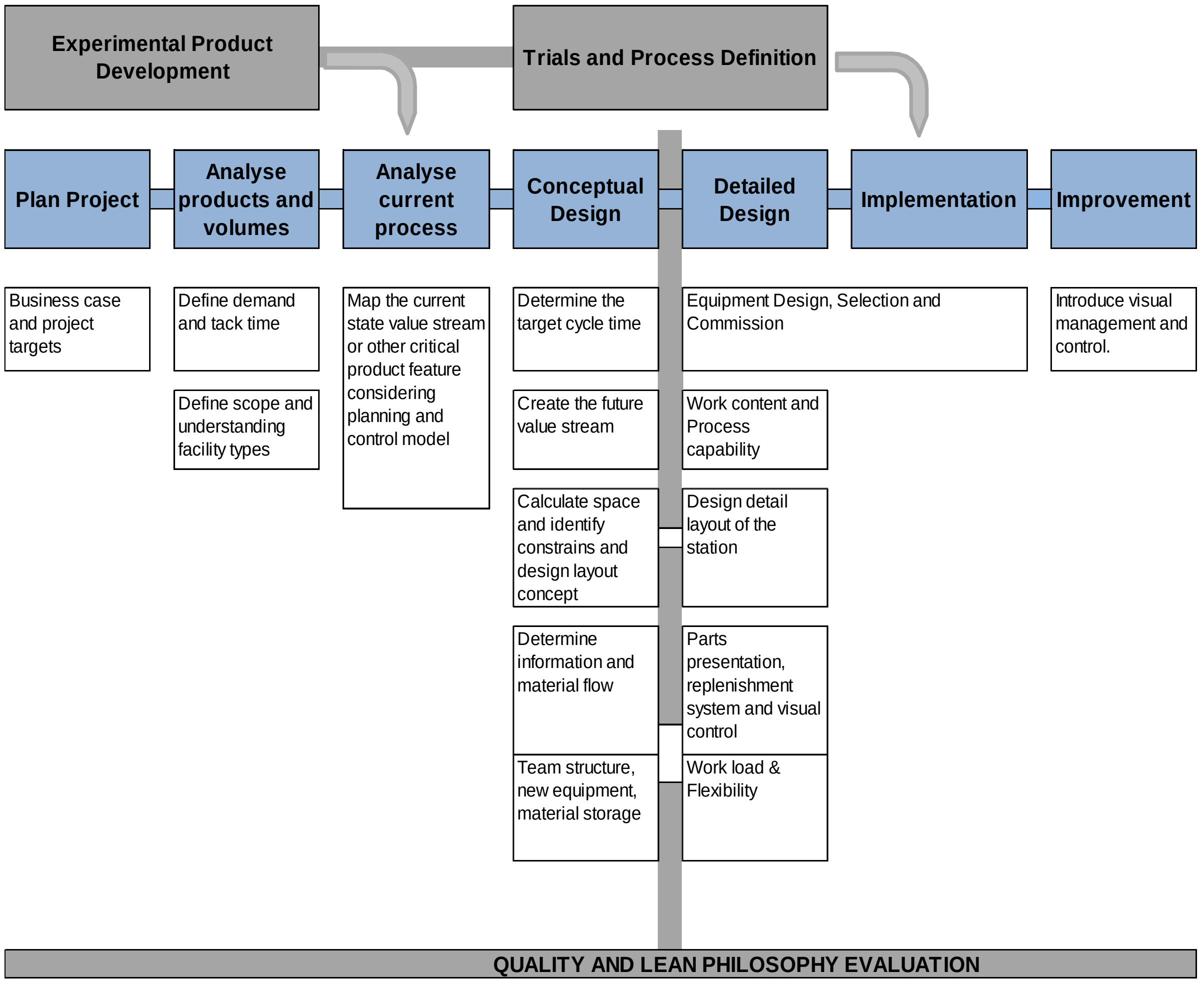


Figure 3.3: Design Methodology and Project Planning for the Thermiculite 866

3.8. The Batch/Flow Comparative Matrix for Thermiculite 866

The aim of the Thermiculite 866 project is to design and commission the implementation of a high volume production line or batch process to provide gaskets for the SOFC industry that may generate £7m per annum income to produce a good financial return. The Thermiculite 866 production process requires accurate controls to warranty product's quality. For this reason, a SAQFD was developed to define the major requirements in the future production line (Yumbla, 2011). This Novel-QFD approach delivered strategic alignment in addition to engineering and customer requirements.

In the literature review, several strong reasons were presented in order to promote implementation of flow line, although, further analysis needs to be conducted to design a suitable production solution for Thermiculite 866. SOFC technology has been developing for the last eighty years and its high technical requirement and expensive materials have not permitted to start high volume production regimens. For this reason, the SOFC industry has had to reduce contact with high volume production line challenges. Flexitallic will face several challenges such as improved operators' skills and closer operation's management.

At Flexitallic, the Thermiculite 866 demand has been forecasted to increase three hundred times compared to the current demand during the next three years. This means that the Thermiculite 866 implementation needs to be highly reactive to considerable acceleration of the demand by 2015. For this reason, the new Thermiculite 866 production line requires a modular concept to justify budget expenditure for the next three years.

In addition to the SAQFD, this thesis suggests a novel comparative approach between batch and flow manufacturing to justify a strategy and future expenditure in the implementation of any high volume production line. The layout can be easily defined by using the link to the material flow and process flow. In fact, the material flow depends on the layout, but a particular layout can vary according to the operation. Consequently, this section proposes a novel and structured matrix to evaluate the product and operation according to different production parameters such as product, process and material supply. This approach supports the principle of Strategic Alignment for the SAQFD.

The novel approach in Figure 3.4 was defined by the author and aims to provide a guide in the decision making for the future production strategy considering flow and batch. This methodology intends to guide stakeholders and other members in the team towards the right direction regarding utilization of resources. The first column, in Figure 3.4, displays three concepts required to achieve Flow, and the difference with Job Shop and Batch operations. On the top of the matrix are displayed different levels regarding Lean Manufacturing controls that promote reduction of variation in the process. The sloped arrow represents the additional controls required to achieve higher Lean Manufacturing levels to support flow process. Finally, the Thermiculite 866 project is represented by the box in the bottom (titled Thermiculite 866 Project) and some specific improvements of the current experimental production line such as layout redesign and the SAQFD. The matrix proposes to evaluate three production features:

1) Product
2) Process control
3) Production control

These points define the required action to pass the barrier between batch and flow represented by the vertical grey stripe.

This innovative approach to design and implement a flow line aims to evaluate different important aspects to achieve flow production “benefits”. The novelty of the matrix in Figure 3.4 is implicit in the proposed evaluation for the analysis of current and future manufacturing process. For this purpose the matrix evaluates three major aspects:

1) Shop floor management
2) Manufacturing process type
3) Future project requirements

Shop floor management is represented by the upper part of the matrix where the sloped arrow represents the additional controls required to achieve better management and Lean Manufacturing levels to support flow process. For example, a job shop type process operates successfully using batch flow concepts and basic shop floor management such as sorting, straightening, systematic cleaning, standardizing, and sustaining (5s). In contrast, a continuous flow process (right hand side in Figure 3.4) needs at least five management control implemented on shop floor: Material Requirements Planning (MRP), workload balancing, pull methods implementation, standardization of process accomplishment, and operation control. The second aspect to be evaluated is the process type which is displayed in the first column on the left hand side. It displays three product and line features to achieve Flow: product, process and logistic supplier. These major "*features*" establish differences between job shop and continuous flow. For example, job shop layout is known for being a flexible process while in contrast continuous flow is particularly rigid for mixing production. Finally, the Thermiculite 866 project, which is the future project requirements in Figure 3.4, is represented by the box under the main chart. The box and arrow represent required line improvements such as layout redesign and SAQFD. The Thermiculite 866 project would permit to design a production line and improved management on shop floor whilst promoting continuous flow.

The dots in Figure 3.4 summarize the product characteristics and the required operational improvements to implement and achieve the reliability of a high volume Thermiculite production line. The dots at the left hand side of the "barrier" represent the current possible limitation to achieve continuous flow. To summarize, two of those requirements: Pull control and control boards will be achieved with the implementation of the Thermiculite 866 project, although, there is a product volume demand that is a fundamental requirement to get the advantages of flow concepts.

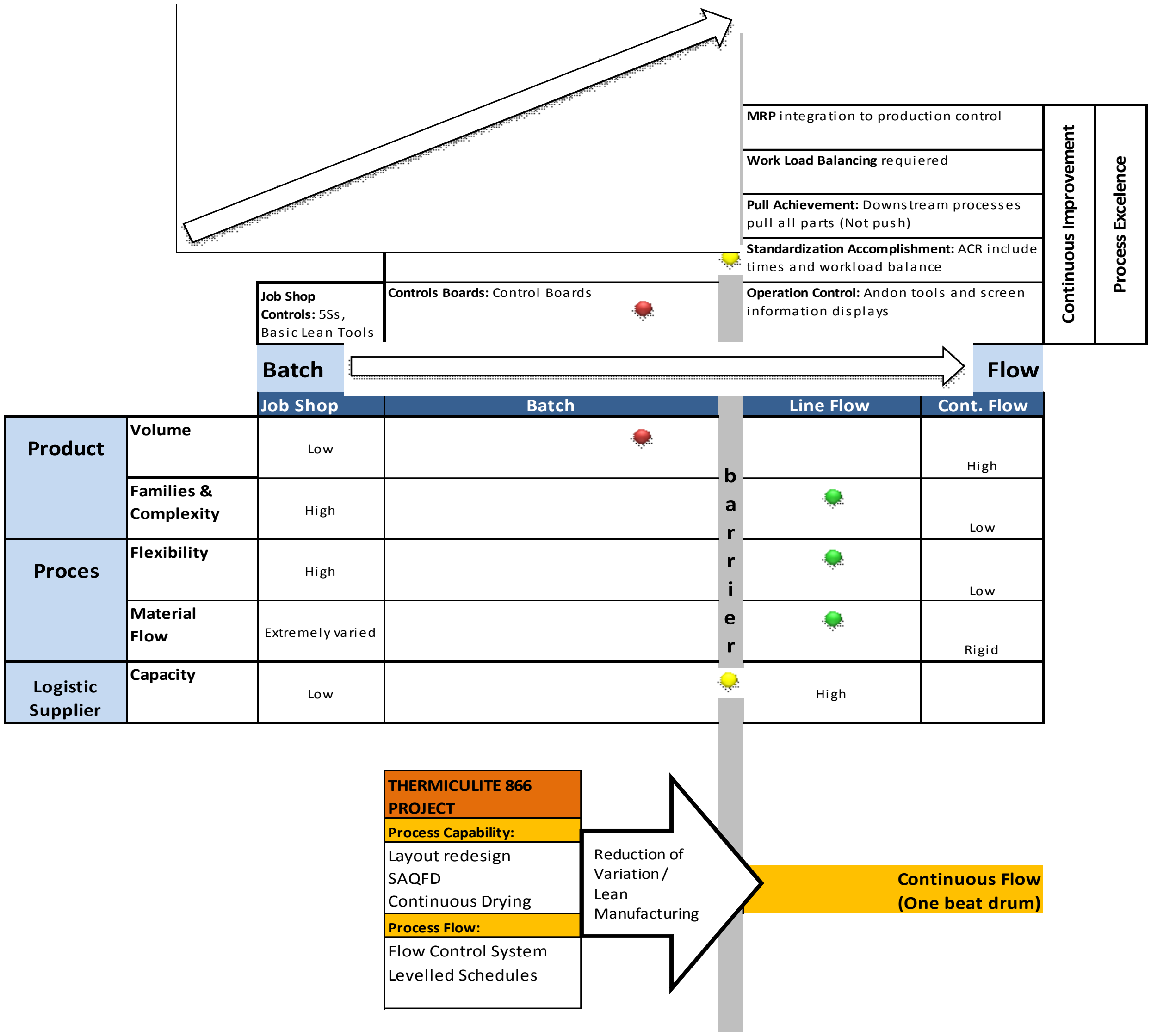


Figure 3.4: Batch / Flow Comparative Matrix

Furthermore, the product complexity and process flexibility provide great conditions for implementation of flow concept. In contrast, there are two required improvements (dots on the “barrier”) in order to switch from batch to flow.

This novel analysis proposed in this thesis permits engineers and designers to envisage the best option to be considered during design of the future production line. In addition, this methodology incorporates important commercial awareness to involve other departments in the organization. For example, accurate demand and material supply figures are valuable input for design and invest decision in the line implementation. To conclude, the batch flow comparative matrix provides a structured representation of requirements to transform a job shop process into a continuous flow concept. The Batch / Flow Comparative Matrix provides key insights to define project investment considering important product features and demand requirements that would justify the change to flow.

3.9. Advantages of the SAQFD Compared to the Classic QFD

Lean Manufacturing and TQM techniques have been providing countless benefits to the industry. Although, assessing and evaluating those benefits is relative and intangible in to lots of the cases. In fact, expenditure for Lean Manufacturing and TQM implementation is sticky to justify in most organizations. For theses reason, the advantages of the proposed SAQFD will be restricted to analytical evaluation of the new features of the SAQFD. The flexibility of the classical QFD permitted to reduce one house in the example in Figure 3.2, which means a potential reduction of 25% in time required to run the QFD exercise. Finally, further advantages of the proposed methodology can be assessed by defining the benefits delivered by the SAQFD constituent sections. These sections are: mission & vision, Workforce Alignment and Strategic Alignment.

Mission & vision, marketing plan and corporate strategy: This fundamental principle might be difficult to define at SMEs, but will set some important questions and statements before starting the SAQFD. This is one of the key improvements of SAQFD: management involvement. This is a positive invaluable improvement compared to the original Akao’s original QFD developed in 1978.

Workforce Alignment: This is a clear extension of the Mission & Vision where the workforce is aligned to promote concurrent participation and related benefits. These last two facts promote better and quicker product development.

Strategic Alignment: This key element of the SAQFD can reduce loops during product and process development by a by promoting good analysis. In addition, the definition of variables would reduce the relationships and prioritisations of product features which reduce time.

In conclusion, SAQFD potentially can reduce 25% of the classic QFD practice and propose higher correlation between management and R&D team for product development.

3.10. Chapter Summary

Therefore, the SAQFD is proposed to “force” product features according to “inherent” commercial strategies. The main streams of influence and information in this novel-QFD are: Workforce Alignment and Strategic Alignment. Finally, several plant design methodologies such as the product/volume-layout/flow matrix and Murther’s method are described in order to introduce the design methodology and project planning for the Thermiculite 866. This structured design methodology intends to lead the Thermiculite production towards manufacturing excellence.

Chapter 4 will develop and transform the concepts covered in Chapter 2 in order to define novel methodologies for plant design and project management. First, the Flexitallic vision and mission statements will be analysed as to how they are cascaded to the objectives and define specific stakeholders’ priorities. A detailed organizational chart is displayed to accomplish Workforce Alignment explained in previous sections.

4. CHAPTER 4

STRATEGIC PROJECT MANAGEMENT AND STRATEGIC ALIGMENT IN THE SAQFD

As Esan, 2007 claims, just as with quality and environmental management systems, change is no longer regarded as a strategic option but a requirement for companies (Esan et. al 2007). Specific methodologies, which are often used individually, were explained in the previous Chapter. This section aims to introduce a detailed view of the entire management methodology used to design the future Thermiculite range production line. The project success depends of the team organization and the accuracy in the analysis of each stage. In addition, this section exemplifies how objectives were cascaded from vision/mission levels.

4.1. Resource Management and Objectives Definition

At Flexitallic, the concept of quality is a general concept that has been sporadically spread in the organization through messages and customer requirements. This key aspect is compiled in Flexitallic vision/mission statement:

"*Creating an effective, safe and sustainable environment exceeding the needs of industry*"

This general approach should lead to more specific purposes generated by top managerial levels and communicated to all levels in the organization. In fact, this information should be cascaded within the organization using specific objectives. For this reason, a more specific and measurable objectives for Thermiculite using Flexitallic vision was defined by the author of this research.

Objective 1: To ensure the Thermiculite 866 accomplishes the quality expectations of customers whilst reinforcing its manufacturing process.

Objective 2: To contribute to the improvement of the customer satisfaction indexes and support Flexitallic quality service management.

Thus, the meaning of quality to an organization represents a measure of excellence to achieve uniformity in products and services. This concept must be spread in the organization through more specific objectives and explanatory for downstream levels. Sun (1999) claims that there are two distinctive approaches regarding the implementation of quality controls and standards. The philosophy of quality is affected by different drivers such as culture of the company and industry. In addition, change can only occur if someone cuts through the morass of rules and regulations and comes to an agreement on what is really important —such as organisational vision, mission, and values (Choueke, 2000).

The so-called majority of international quality standards such as ISO first became a concern among the military at the end of the 1950s. Today, ISO is considered the cornerstone of some companies in Europe including Flexitallic. The ISO certification is considered essential for QA in procedures and product quality. Even though, only implementing ISO 9000 will not contribute as much as TQM as usually assumed by managers. In fact, Juran and Gryna (1988) has pointed out that ISO 9000 failed to include some essentials to obtain world-class quality, such as: quality goals in the business plan, quality improvement at a revolutionary rate, training in managing for quality; and participation by the work force. Sun (1999) suggests incorporating both approaches ISO and TQM in companies. In Flexitallic, ISO standards are cornerstone in the organization and manufacturing process, although, TQM has not been fully adopted and adopted by Flexitallic. The Thermiculite 866 project will introduce first notions of TQM by engaging the manufacturing quality team from the beginning of the product development. In addition, and most importantly, new TQM tools such as QFD, Failure Modes and Effects Analysis (FMEA) would be introduced.

4.2. Management of Change

There are multiplicity and variety of change theories available in handbooks, textbooks and courses, although the practice of change management is problematic. These comments come from senior leaders, middle managers, external consultants, and teams who consider there is not a unique approach to cope with the difficult task of changing an organization (Andrews, Cameron, and Harris, 2008). According to Meier (2011) change capacity is “the ability of the company to produce solutions (content) that respond to environmental evolution (external context) and/or organizational evolution (internal context) and to implement these change processes successfully within the company (process)”. This approach requires a collection of resources and skills to adopt new practices. In other words, the organization itself may become the tool to manage change and to overcome barriers. The flexibility of the organization structure also plays a role in the implementation of the change. Every change varies in depth, vigour, and the time required for implementation. The change proposed in this thesis is restricted to the Thermiculite 866 project, which is projected to be implemented during a two year period. Considering the approach proposed by Meier (2011) the change at Flexitallic will have three major approaches:

- Organizational Development: the key methodologies are participation, communication, training and incentive. This will be focused and limited to Thermiculite section where one Operator has been trained and would be promoted to a higher position as Technician after the Lean Manufacturing training is completed by February 2012. This first step aims to promote a greater project to involve more operators with training and personal development. This approach intends to change individuals and consequently promote collective change thought training.

- Political Approach: To adopt change it is important negotiation to ensure the convergence of interests. For Thermiculite 866, it is required to agree with managerial levels about resources needed to be allocated for change implementation. SMEs might be sceptic to invest in change because it usually produces an out of comfort zone effect in the organization. In fact, change should come from top managers to bottom levels in order to promote commitment and to allocate resource in the process. Therefore, the implementation of change in the Thermiculite 866 project was agreed with my supervisor at Flexitallic who is the Operations Director responsible for operational and supply chain issues for the site.

- Incremental Strategy: Introduce change in a specific section for an incremental change reduces destabilization and risk in the organization. The implementation follows a strategic model where after being implemented in the Thermiculite 866 will be spread in other sections of the business. The aim of this approach is to promote Lean Manufacturing implementation at Flexitallic by the Thermiculite 866 case study. Operators and managers need to experience benefit and achievements in Thermiculite area before adopting change in the business. In fact, the opposite approach of allocating huge resources in reduced time to produce change is not applicable at Flexitallic due to the deep change required. Finally, the change will be based on the PDCA cycle that provides a controlled methodology for incremental change.

This thesis will cover three major management changes in the organisation during the design and implementation of the Thermiculite 866 production line:

1. Concurrent Engineering as a fundamental part of project management.

2. Business/commercial awareness as fundamental criteria for research & development.

3. Introduction of world class KPI in the Thermiculite 866 line.

These three points are defined in the following three sections.

4.3. Concurrent Engineering as a Fundamental Part of Project Management

According to Gascoigne (1995) concurrent engineering was heralded as the new panacea for manufacturing that intents to reduce product and process development times whistle introducing new dynamics in the organization. The new project management approach intends to involve R&D team into life-cycle cost and Operations as a key driver during the process development. Barker (1999) claims that an element frequently missing from organizations is that of team learning. Team learning and involvement is crucial at Flexitallic considering that operations was not fully involved during product development in previews projects prior the Thermiculite 866 project. During the project, FMEAs and SAQFD were the mechanism to promote concurrent engineering and communication between operations and R&D.

This knowledge sharing process played a fundamental role in generating new ideas and creating opportunities. However, there were major gaps created by employers not willing and able to share their own knowledge and assimilate the knowledge of others. In fact, Hendriks (1999) argues that knowledge sharing within organizations can be seen as a multifaceted, complex process that involves intricate human behaviours. Before Thermiculite 866 project, it was a common practice to base commitments on informal communication and blur roles that created overlap of efforts and “over the wall syndrome”. For this reason, Thermiculite 866 project intended to define formal channels for compilation of information such as the implementation of business control board on shop floor and effective regular meetings for following up. After one year and a half, the relationship between Operations and R&D has reached a balance and good communication for product and process development.

4.4. Business/Commercial Awareness as a Fundamental Criteria for R&D

As the bridge between scientific discovery and commercial application, engineering provides a great opportunity to support the process development and product launch. At Flexitallic the links between operations, R&D, applications and sales need to be enhanced to warranty successful product launches. During the Thermiculite 866 line design, new concepts, such as payback periods and forecasted demands, were introduced in the project management. In Section 5.2, new concepts such as “effective work load per kilogram produced” and process capability analyses, were key inputs for equipment selection. This change in equipment selection process created “restrictions” and a clearer frame for the R&D team. In the past, they used to define important process parameters without future commercial requirements.

As result of this practice, oversized equipments and expensive indirect materials were introduced. In addition, most of these cases produced inefficient environments for operations and poor quality control during process. Those equipments were the result of product development and do not consider future demand nor product improvement. Under these conditions a project might end with expensive equipment rusting in a corner and a group of poor motivated people in the organization. In addition, the company would lose market opportunities and money that would be used in other area. It is not a secret that 70% of the product life cost is spent during R&D stage. For this reason, Flexitallic needs a clear vision and a good strategy to cope with future commercial requirements.

Section 5.2 shows few manufacturing capability analyses that produced one of the major changes in the future Thermiculite 866 production line, which is the incorporation of a flow process and discard of previous batch concept. This change was supported by technical facts, collaboration of the R&D team, and approbation from project stakeholders during monthly presentations.

4.5. Introduction of World Class Key Performance Indicators Lean Principles in the Thermiculite 866 line

In 1950, W. Edwards Deming lectured the Union of Japanese Scientists and Engineers as well as major leaders of Japanese commerce and industry. In this time, Japanese engineers, managers, and industrial leaders were very interested in learning how to improve the quality of their products. During the first two years Deming emphasized the need of quality of management and the importance of statistical analysis (Petersen, 1997). This is the trigger for several fundamental concepts about vision, strategy and tactics that can deeply transform organizations in different businesses from educational, medical to manufacturing. The results of this philosophy were seen in 1960 after Japanese industry development using Deming's philosophy and paradigms. In the same year, Deming was decorated with the Second Order Medal of the Sacred Treasure by the Emperor of Japan. However, this philosophy seems to be based on basic concepts that might be simplified in the following words: change, transformation and the famous Plan Do Study Act (PDSA) cycle. Consequently, the implementation of change is intrinsic to Lean Manufacturing implementation.

The introduction of KPI with a Lean Manufacturing approach might be the ultimate change that will redirect the Flexitallic business management. Organizational development in Lean Manufacturing understanding is critical to start an incremental change to better Operations control. After the first change has been implemented then the organization learns by constantly implementing change and grows in experience for future the implementation of change. This creates capacity to change and promotes aptitude for learning. This is Deming's legacy for several organizations around the world, and aim for several companies around the world. The first step to change into Lean Manufacturing will be on production control using daily and monthly performance charts recording quality and production indexes. Raw materials will be controlled using pulling systems and inventory records. All these things together are the first KPIs to be introduced in the Thermiculite 866 production control board, which will use the PDSA cycle. At the moment, only basic Lean concepts have been implemented in the Thermiculite 866 line, and most of the PDSA cycle has been applied during the equipment design stage. The full deployment of KPIs will be seen when production has achieved at least the Start of Production (SOP) that is forecasted for 2016. The current development of the production line requires quality checks such as the Weight Per Unit Area (WPUA) that will be fully analysed in Section 5.7.

4.6. Thermiculite 866 Project Management

Project management is not a one-person enterprise; the organization team must be aligned and involved in different fronts of the project. On top of the project company directors define project objectives and these objectives must satisfy stakeholders. Payne (2005) suggests the following structured plan to meet stakeholder's needs:

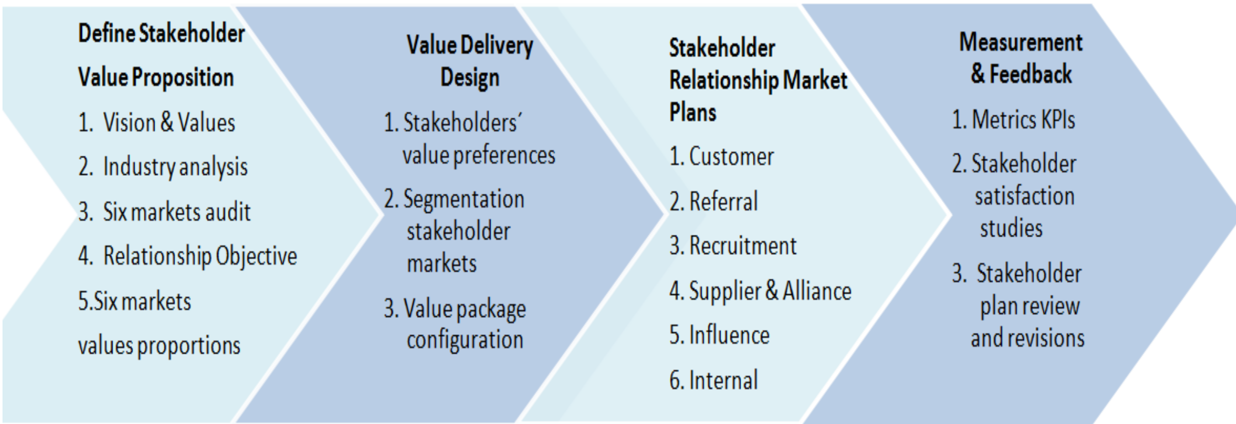


Figure 4.1: Stakeholder Priorities and Values

For the Thermiculite project development the following points of this stakeholder relationship planning framework needs to be highlighted:

- Define stakeholder value propositions & industry analysis: Flexitallic provides a quick reactive service where customers are always first. In contrast, the Thermiculite 866 would be the first high demand product at Flexitallic. This type of industry requires a good understanding of the market and cannot rely on the manufacturing capacity to respond last minute customer requirements. In fact, the future of Thermiculite 866 relies on long term planning process.

- Value Delivery Design: This item involves the delivery of products or services to customers and also the potential value exchange with other stakeholders. This is a key point for Thermiculite 866 that should be deeply analysed in order to define the future market that needs to be targeted.

- Stakeholder Relationship Market Plans: Different stakeholders have specific interest in the development of the Thermiculite 866. Some of the Top Managers are considering this product as the future star product in Flexitallic. Although, any high expectation must be validated by the real SOFC market. There are other stakeholders that are a little sceptic about development of the SOFCs technology that has been developed for almost eighty years.

- Measurement & Feedback: In practice, Stakeholders can be considered as customers whose expectations can be identified by conducting surveys. In the first stages it is required to understand the objectives that would conduct a research to collect data and develop a questionnaire.

4.7. Project Team Structure

It is not a secret that organizations success relies on human resources, and this project is not an exception to this rule. The author of this thesis, with the support of the directors at Flexitallic, defined the team to perform the design and implementation of the future production line. This is the first time that such a practice was adopted at Flexitallic, and certainly produced concerns within the R&D team. They used to design and implement equipment without operations' involvement, and now for first time a director from operations is involved in the project as stakeholder and decision maker. The definition and communication of the members' roles promotes ownership and clarity about individual responsibilities. The Flexitallic team has been divided into three different hierarchical groups. Each group has been described and classified according to their role in the project: project owners, project coordinators and executors and project coordinators and executors.

- Project Owners - They have high interest in the commercial and economic success of the project. Their main goal is to accomplish the levels of production, quality and flexibility required for the future Thermiculite 866 demand. In addition, they are looking for revenue with the clarification that states that due to the novelty of SOFCs the investment is not restricted by payback periods.

- Project Developers - They are the experts in product features, materials and manufacturing process. In addition, in this group, it has been included both academic supervisors who transferred knowledge from the UoB to Flexitallic. Most of this technical support was in TQM and Lean Manufacturing implementation.

- Project Coordinators and Executors - They are the white-collar workers that perform the required tasks to support the design, commissioning and implementation of the Thermiculite 866 production line. They are considered “partial-stakeholders” because their role changes from internal customers to providers along the project implementation. Figure 4.2 displays the team structure that was set up at the organization and officially presented to all levels in Flexitallic.

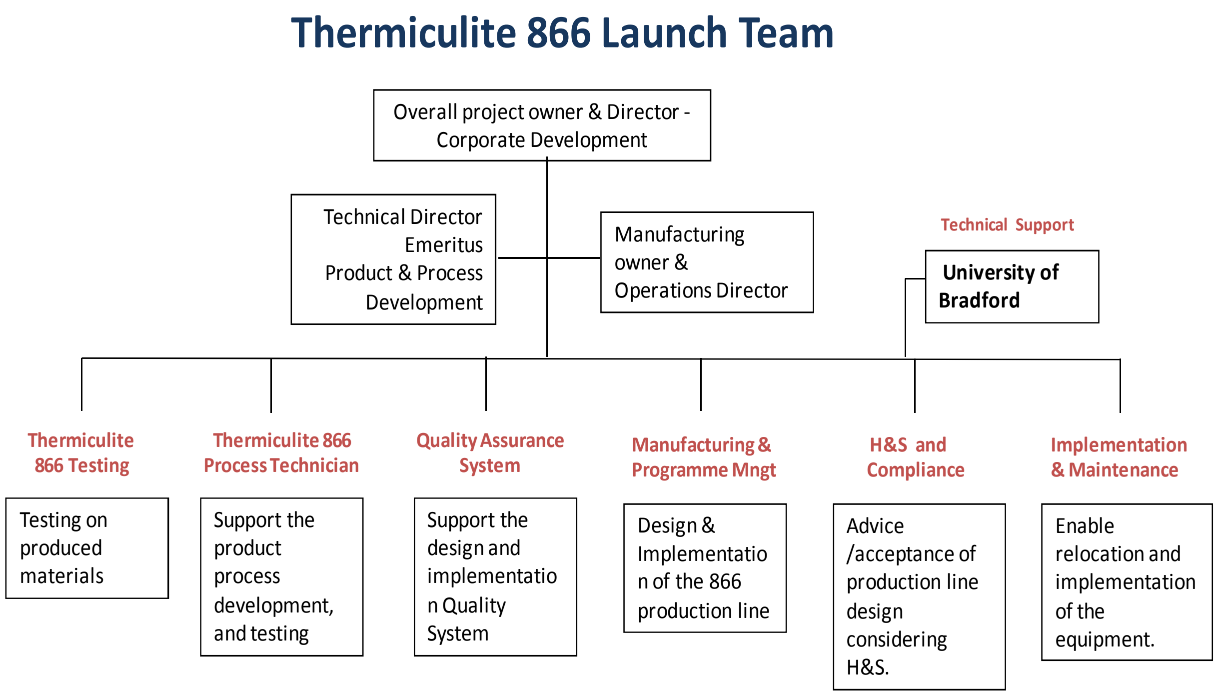


Figure 4.2: Thermiculite 866 Project Team

To keep the team dynamic; meetings were set up at least once a month**.** During these meetings needs and expectations were collected during the last ten months. Moreover, the three groups previously mentioned can be split in two main groups: the academic stakeholders and the company stakeholders. Where the first group promotes capturing and transfer of knowledge to Flexitallic. However, the aim of the project will always be lead by the company's stakeholders.

4.8. Planning and Management Strategy

This thesis has previously presented two initiatives in Sections 2.13, Appendix 1 and 2 to design the layout of the Thermiculite 866 future production line and specific aspects of product QA. There is extensive literature about the use of TQM and Lean Manufacturing techniques, although the utilization of such approaches and their relationships depend upon each specific project. This section aims to explain the arrangement proposed by the author and interrelation of the SAQFD, master plan and Batch Flow Comparative Matrix to support the Thermiculite 866 project. The author developed a project management plan based on three management levels for product development and launch in market:

a) Marketing and Corporate Strategy

b) Product and Process Development

c) Production Management

Furthermore, the project has been developed in seven major stages:

1. Plan Project
2. Product and Volumes Analysis
3. Current Process Analysis
4. Conceptual Design
5. Detailed Design
6. Implementation
7. Improvement

In addition, the roles and responsibilities of the project team are considered in the different stages of the project. Figure 4.3 displays the three project management and development levels mentioned above.

The three levels were defined by a hierarchical order with the managerial level on top (Marketing and Corporate Strategy), technicians and product developers in the middle section (Product and Process Development) and manufacturing engineers on the bottom (Production Management). As explained before is important to place in context the SAQFD developed for this project. The SAQFD supports stages two through four where marketing plan and corporative strategies are defined in the second stage by directors and department managers. The project master plan supports the detail design, implementation and improvement stages (Sections 5, 6 and 7) displayed in the bottom boxes in Figure 4.3. Finally, the Batch Flow comparative matrix has been used in the conceptual design (Section 3.8) as an important link between commercial awareness and process development. As shown in Figure 4.3, the comparative matrix is a tool used by manufacturing department that is part of the conceptual design and engage directors, managers and laboratory technicians. The matrix and SAQFD are exceptional examples of concurrent engineering practices used in the Thermiculite project at Flexitallic. Conceptual design section includes trials and system design after evaluating the Batch Flow Comparative Matrix. This leads to the testing and commissioning stages represented by the bottom boxes under stages five and six. In conclusion, the Figure 4.3 displays the Thermiculite 866 project approach regarding roles and responsibilities in the different stages of the project.

The implementation of the Thermiculite 866 Project needs a strategic management and engagement of the organization at different levels. The project team defined in Section 4.3 Thermiculite 866 project management would facilitate change through delivering the message to different levels of the organization and in particular to shop floor level.

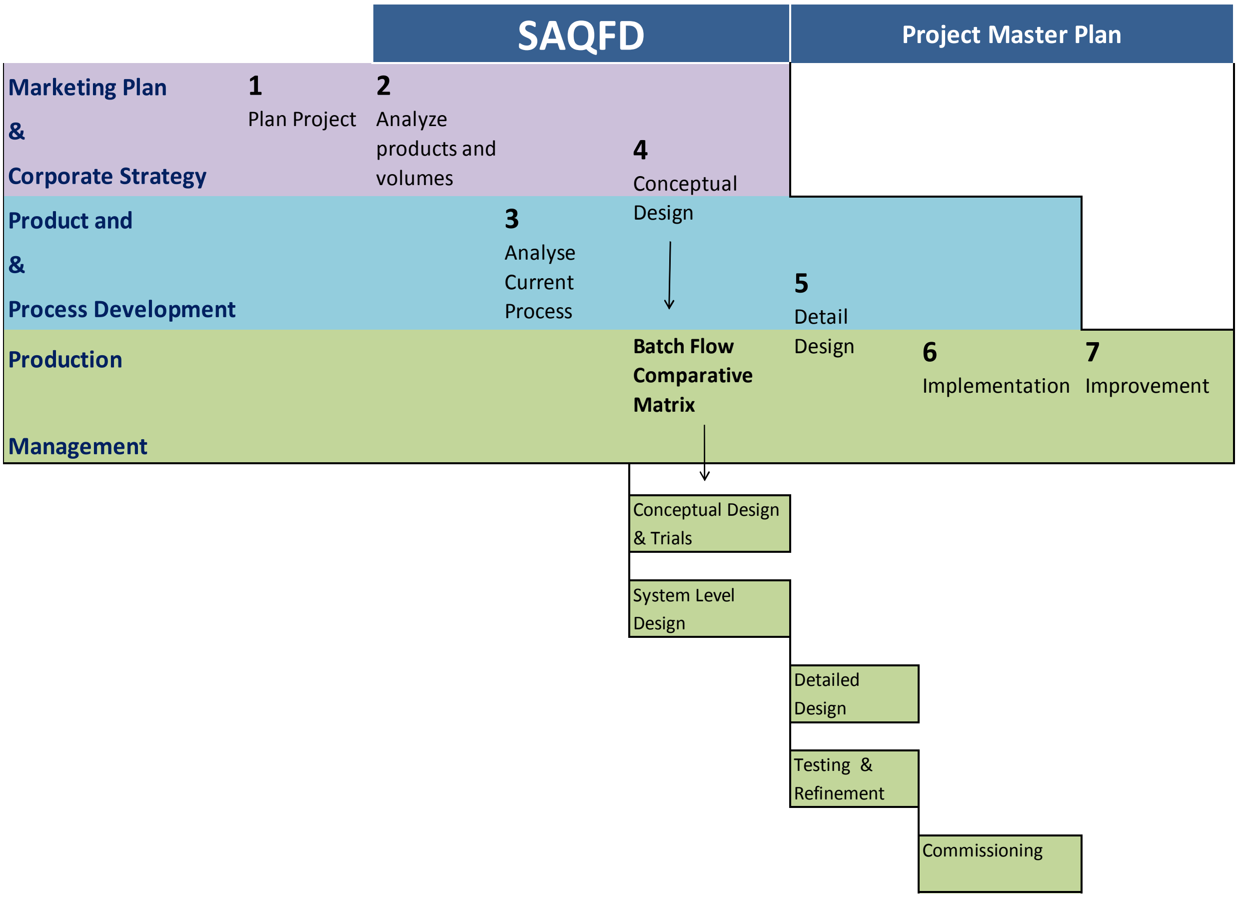


Figure 4.3: Project Management Plan for Thermiculite 866 Project

The implementation of the plan proposed in Figure 4.3 is included in the following sections:

- Plan Project, product analysis and volume forecast (Number 1 and Number 2) have been covered in Section 1.6 and Section 5.2.

- Current process (Number 3) is included in Sections 5.2

- Conceptual Design (Number 4) has been covered in Sections 3.8 with the Batch/Flow comparative matrix that lead to the layout proposed in Section 5.5.

- Detailed design and improvement (Number 5, 6 and 7) of some specific processes are included in Section 5.7, 5.10 and 5.12. The partial implementation of the production line is aligned to the requirements regarding future demand and the launch of the SOFC in the UK market.

Chapter 5 and sections described above describe the partial implementation of the production line achieved until 2011. Finally, a document called Project Master Plan records the implementation of Numbers 5, 6 and 7 in Figure 4.3. The Thermiculite 866 Project Master Plan has 300 tasks defined by the project Team in order to prepare and implement equipment the high volume production line at Flexitallic for the start of production in 2016. It has achieved 18% (50 tasks) of the Gantt chart tasks (Appendix 3) for the implementation of the production line at Flexitallic. The design and the selection of equipment have gone through the process proposed in boxes under conceptual design in the Figure 4.3. For example, the drying and packaging systems are currently in the detailed design stage and it is expected to be fully designed by the first quarter of 2012. In addition, the mixer was already designed and implemented in December 2010. The following Chapter explains the design and implementation of the Thermiculite 866 line according to the current implementation of the production line at Flexitallic.

4.9. Chapter Summary

This chapter introduced the important aspect of product development and project management: organisational vision, mission, and QA based on solid management principles. It was mentioned that TQM is a major driver for ISO 9000 implementation and support of QA in organizations. In addition, this chapter described Project Management based on good understanding of the market rather than relying on manufacturing capacity to respond expected customer requirements. In fact, the future of Thermiculite 866 relies on long planning process supported by measurement and feedback from a structured implementation team. This strategic team has been divided into three different hierarchical groups for Thermiculite: Project Owners, Project Coordinators and Executors and Project Coordinators and Executors.

The Chapter also introduced the reader to the first novel outcome of this thesis: the batch/flow comparative matrix for Thermiculite 866. This chart proposed a novel and structured matrix to evaluate the product and operation according to different manufacturing parameters such as product, process and material supply. In addition, this matrix provided a view of Lean Manufacturing controls' requirements for reduction of variation in the process. The matrix systematically evaluates three major aspects: shop floor management, manufacturing process type and future project requirements. The proposed matrix is a fundamental part of the planning and management strategy in the Thermiculite 866 project displayed in Figure 4.3. Furthermore, this chapter introduce commercial awareness criteria in product development, the definition of formal channels for compilation of information and a proposal for the future introduction of world class KPIs.

Finally, the project has been split in to seven major stages: plan project, product and volumes analysis, current process analysis, conceptual design, detailed design, implementation and continuous improvement. These stages are materialised by 300 tasks defined in the Project Master Plan that is part of the Project Management scheme to implement the production line for the start of production event in 2016.

The following Chapter 5 will describe the design and technical achievements that were possible as results of project management and cultural changes described in previous sections. The process improvements achieved in the project and described in the next chapter are the outcome of utilization of SAQFD and the plant design methodology. To conclude, the next Chapter shows the practical utilization of Concurrent and Lean Manufacturing philosophy that was previously described and adapted for the Thermiculite 866 project.

5. CHAPTER 5

MANUFACTURING PROCESS DESIGN AND IMPLEMENTATION USING A STRATEGIC MANAGEMENT APPROACH

5.1. Introduction

This chapter constitutes the case research or pilot for the theory developed to achieve the business requirements for the Thermiculite project and the thesis research objectives. The structure of this chapter will be regulated by the Project Management Plan (PMP) suggested in section 4.4 which was developed to introduce the SAQFD and the batch-flow comparative matrix in product development at SMEs.

The Thermiculite project is an on going project that is forecasted to reach SOP by 2016. For this reason, it is not possible to demonstrate all the sections proposed as the PMP in Figure 4.3. Even though, the SAQFD which is the core of this thesis has been fully deployed and its specific achievements are reported. The sections reported are the ones achieved during the implementation of the future Thermiculite production line which are linked to the SOFC development on third party companies.

For the purpose of report the pilot, the planning suggested in Figure 4.3 can be summarized in the following sections:

- Plan Project
- Analyse Product and Volume
- Analyse Current Process
- Conceptual Design

- Detail Design
- Implementation
- Improvement

Each section has subsections, for example, Batch-flow comparative is a constituent of the section 4 Conceptual Design. The following sections titles will include a reference to the 4.3 Figure to provide a better reference to the proposed project management and the level of implementation. For example, the Batch-Flow comparative matrix would be 4.1 in the PMP in Figure 4.3.

5.2. Current Thermiculite 866 Production Process

This is number 3 in the PMP in Figure 4.3. In this thesis, no sensitive information regarding the Thermiculite 866 manufacturing process will be published or information considered intellectually strategic in the product patent. The manufacturing process of the Thermiculite 866 has four main processes:

1. Mixing
2. Spreading
3. Drying
4. Rolling (consolidation)

The following diagram shows the different processes carried out to produce the Thermiculite 866 sheets:

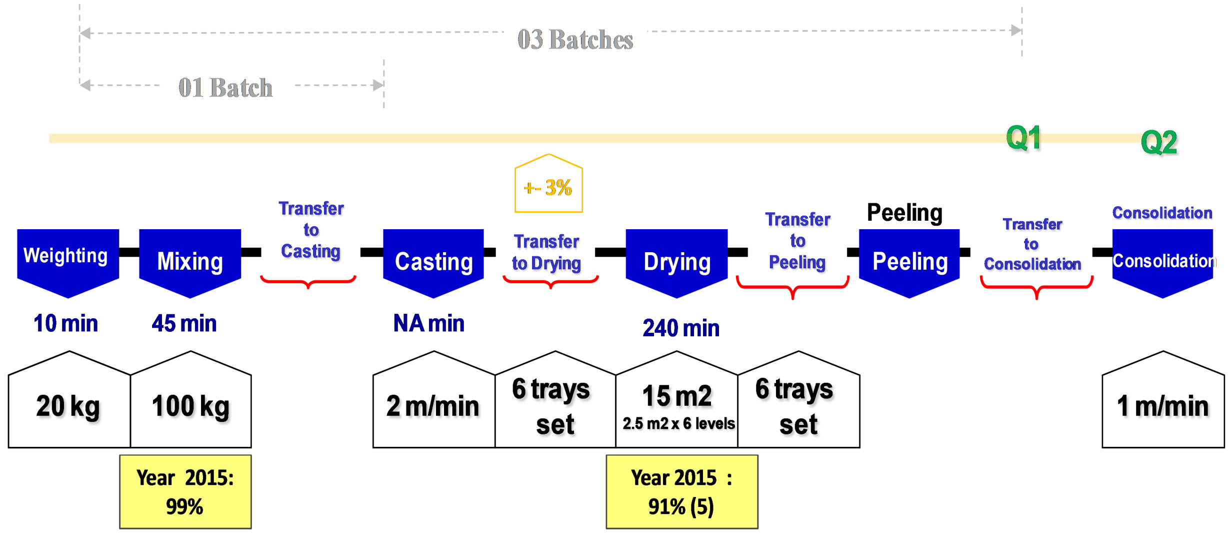


Figure 5.1: Thermiculite 866 Manufacturing Process

Thermiculite 866, as explained in the introduction, is based upon the use of extremely thin, flexible plates of natural mineral vermiculite and another silicate with a plate-like crystal structure, which is perhaps better known as talc or soapstone (Flexitallic, 2010). Using a 0.05 Kg accuracy weighing system, these two materials are mixed with other morphology compatible materials. The little white house-shaped figure in Figure 5.1 above shows the capacity of each manufacturing process. For example, the first “house” displays 20Kg which is the permitted weight that an operator can lift and carry to the scale and 10 minutes is the approximate required process time. Above the graph is displayed the number of batches in-process. For example, three 25 meter lengths batches are the in process inventory from weighting through peeling. This analysis is important to define strategic quality checks to reduce the impact of defects during production. Finally, between the blue boxes is the transfer of handling of the material. For example, a six tray set is needed between casting and drying and a quality observation has been included in orange. The diagram in Figure 5.1 displays the initially proposed batch process, which was the result of scaling up of the current laboratory production methodology.

Flexitallic has already purchased some equipment as part of the process and product development. The following pictures show the equipment which is actually producing Thermiculite 866. This production facility can produce less than 5% of the demand forecasted for 2015. For this reason, there is a requirement to implement a continuous flow line to manage future demand. The mixing system in Figure 5.2 consists of two vessels and a vacuum system that reaches about -800 PSI. Cast facility consists of a 25 meter belt conveyor and a set of blades shown on the right.

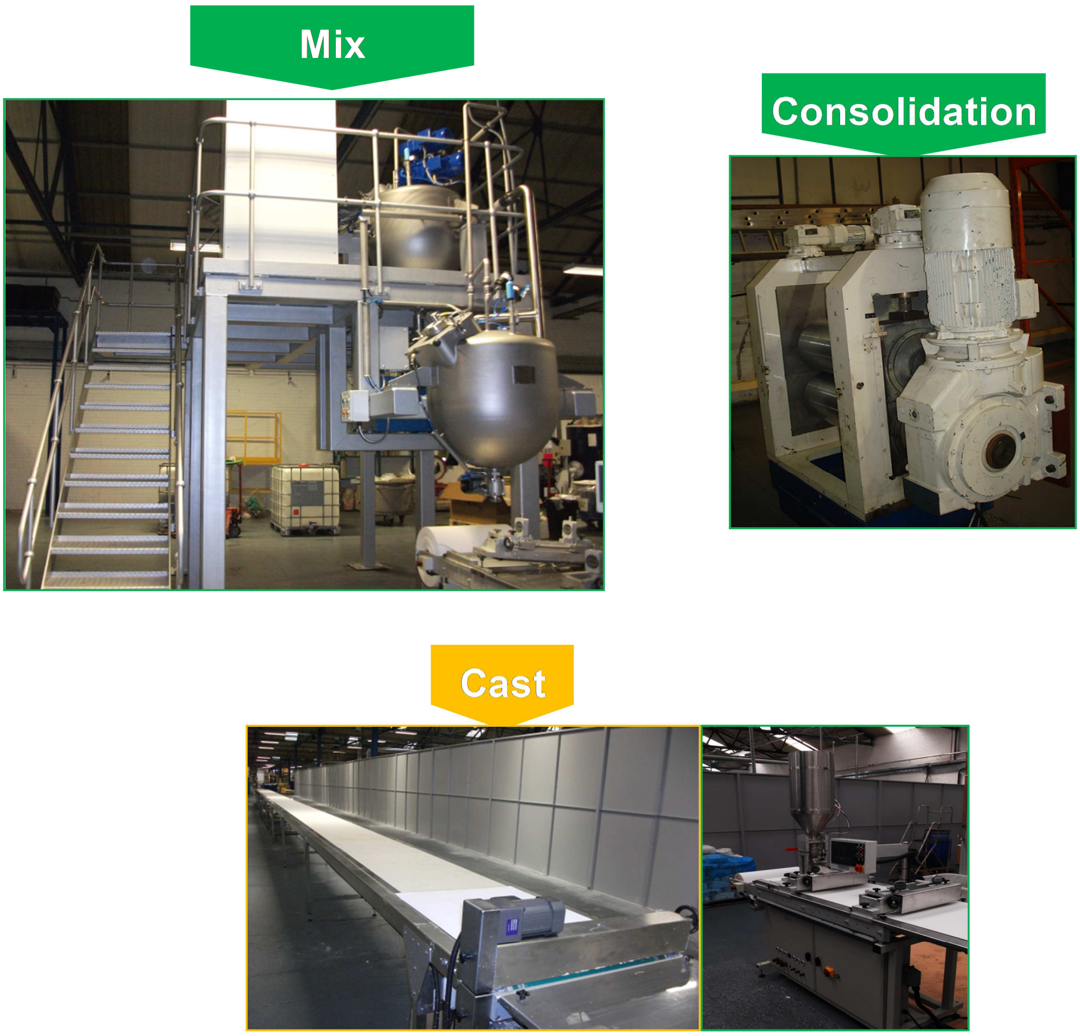


Figure 5.2: Current Thermiculite 866 Line at Flexitallic

Further analysis demonstrates that resources needed for batch manufacturing increase linearly compared to demand. In fact, the initial drying capacity would be replicated five times, which would exceed only with 9% the total demand (displayed in the yellow box in Figure 5.1).

As shown in the batch/flow matrix in Section 3.8, the flow systems provide better support in high volume demands of relative simple featured products such as the Thermiculite 866. Even though there is one important issue to be solved: the product inherent reduced moisture extraction capacity which is the major manufacturing bottleneck. Another important fact to promote continuous flow over batch is all the required handling when the set of trays are transported between processes. The amount of labour involved in the process can be represented by the volume of production against the hours per year utilized to produce these products. The labour used in the production represent manpower and for that reason a highly automated production system would require less manual intervention. As shown in Figure 5.3, the gap between the labour requirements for batch process (6833 labour hours per year) and the line flow (1152 labour hours per year) grows exponentially.

Due to the relative simple manufacturing process: weight, mix, cast, dry, peel, cut, rolling and packaging, it was not necessary to perform a value stream mapping exercise to recognize production bottle necks and future improvement requirements. By 2015, considering the drying solution capability and the mixing system that was implemented, the planned utilization of the process capabilities will be: 8% of mix and cast, 88% of dry, 2% of peel, cut and packaging.

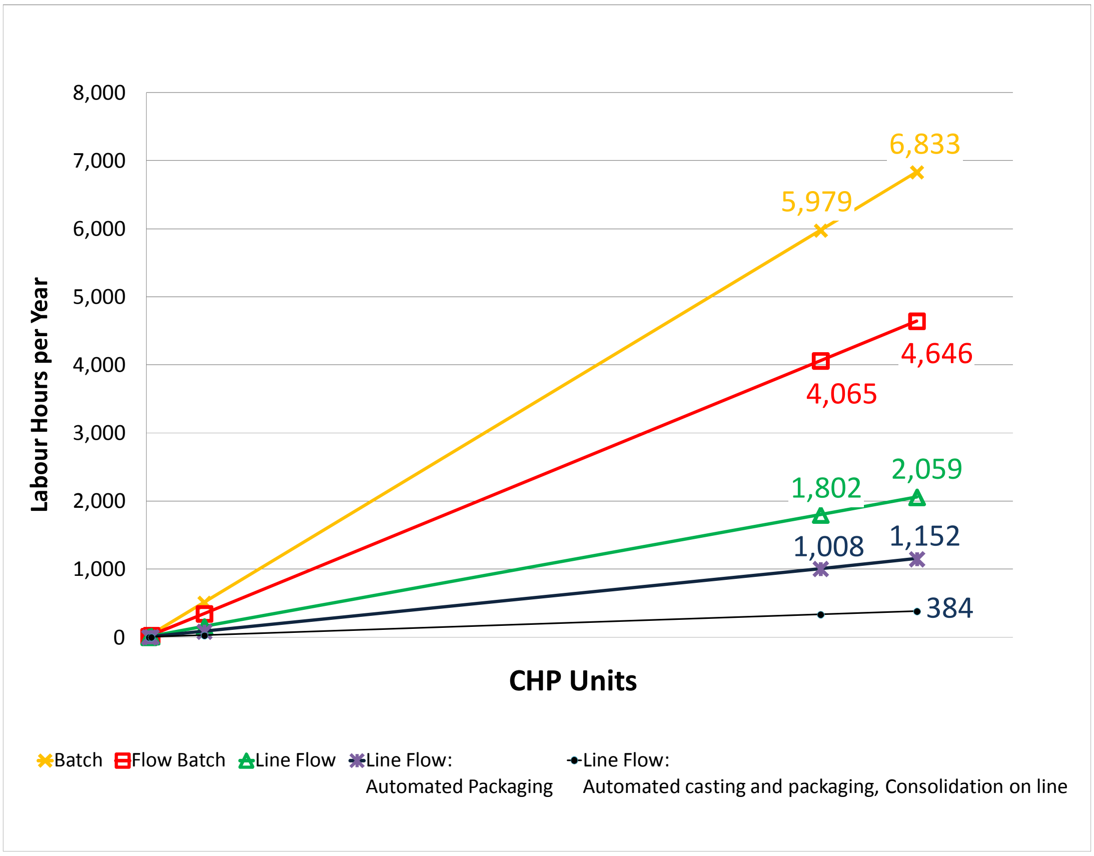


Figure 5.3: Labour for Different Thermiculite 866 Manufacturing Strategies

An analysis of the time involved during the manufacturing process provides a good idea about bottlenecks that need to be eliminated using automation or flow strategies. Figure 5.4 displays the approximated working time per kilogram. This concept developed by the author provides figures about time expenditure in the particular manufacturing processes in the Thermiculite 866. For example, the peeling process requires 6.3 minutes for each Kilogram produced with batch and flow batch strategies. In contrast, this process would not need any intervention from Operator as seen in flow line and flow line & automated packaging.

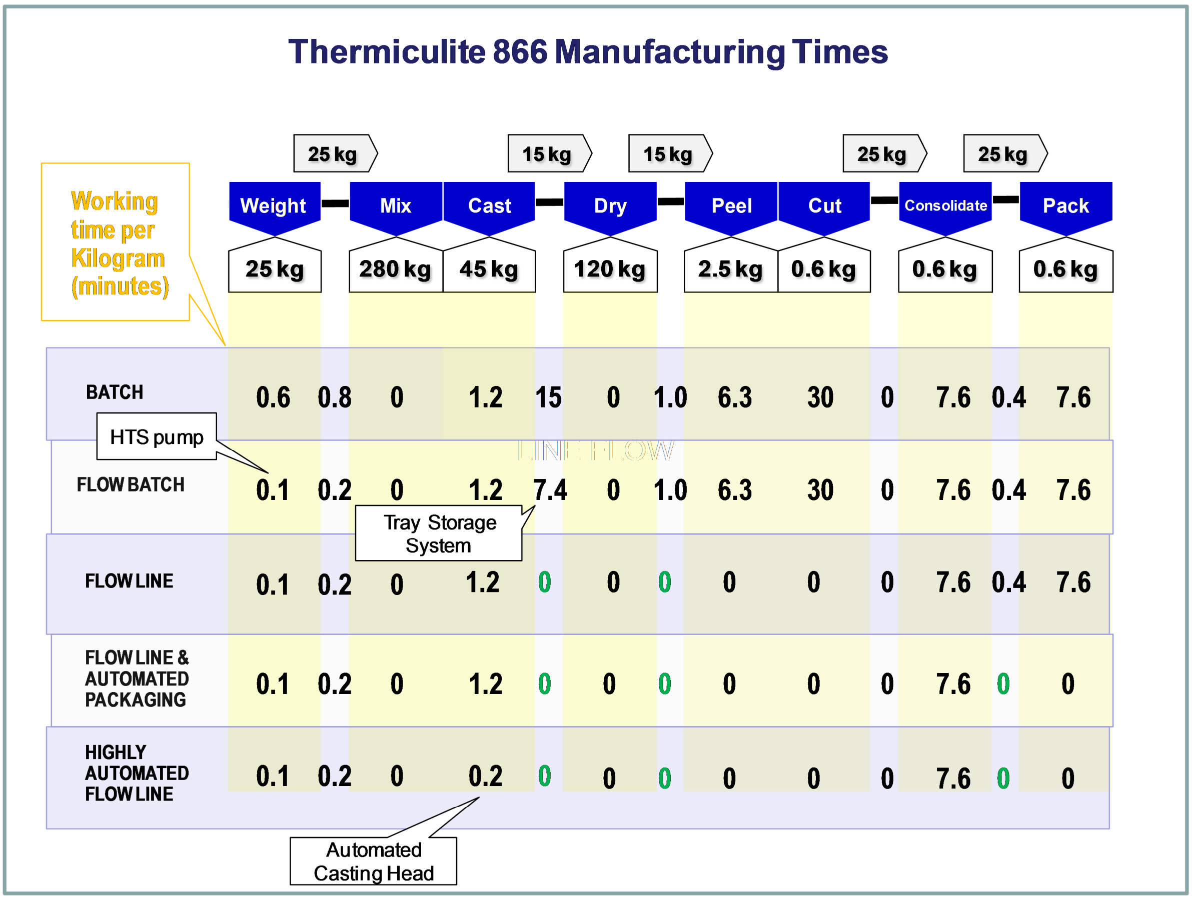


Figure 5.4: Manufacturing Work Load Times

This chart developed as part of this thesis provides a better understanding of working time loads required in different strategies and using different approaches. Once the demand increases the manpower needs to be increased as well. From Figure 5.4, it can be noticed that flow line & automated packaging is the most efficient option with a total of 0.5 hours per kilogram if consolidation is part of the continuous flow scheme, although, this highly automated scheme would require an important investment in equipment. For this reason, the development of the Thermiculite 866 line is led and framed by SOFCs customers and other industries requirements. In fact, this constitutes a particular vision and strategy for the Thermiculite 866 production line: Identify and design a flexible manufacturing system in terms of production capacity whilst developing the process and QA.

Now that product features, general process and particular vision for the line development have been presented, the reader can return to the SAQFD that is part of the strategic project planning in the Section 4.4.

5.3. Case Study: The Strategic Alignment of Quality Function Deployment for Thermiculite 866

This is a top requirement in the PMP from Figure 4.3. As explained in Section 3.2, SAQFD is performed to promote quality and quick product development. The SAQFD for Thermiculite 866 starts with the Organizational Alignment or Workforce Alignment as mentioned in Chapter 3 and fully defined in Chapter 4 by the organization of the Thermiculite 866 launch team. Figure 5.5 summarise the SAQFD for Thermiculite 835 using the methodology proposed in Section 3.6:

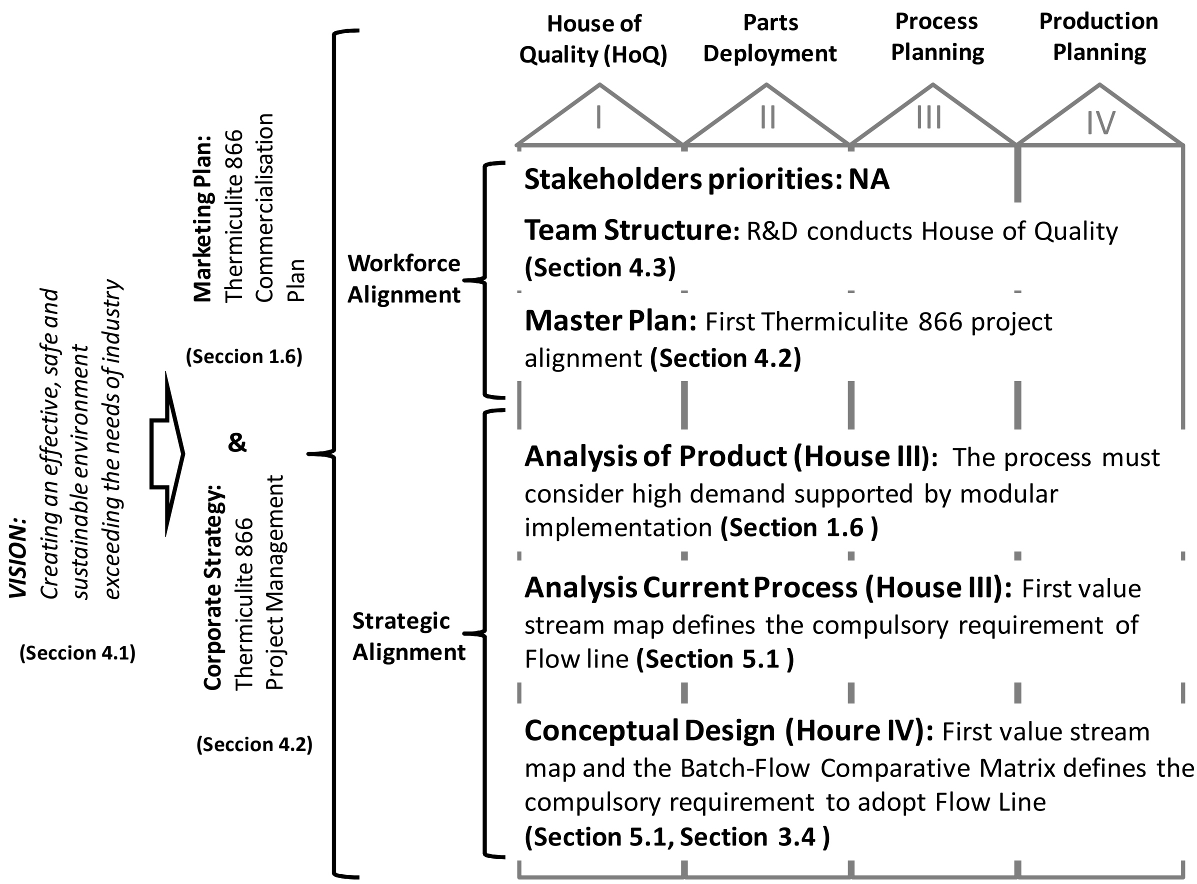


Figure 5.5: The SAQFD for Thermiculite 866

In Figure 5.5, each section specified in brackets is linked to analysis conducted in previous chapters. For example, the conceptual design, which affects House IV requirement, is developed in Sections 3.7 and Chapter 5 in this thesis. Next paragraphs aims to demonstrate the dynamics to define the proposed SAQFD for Thermiculite 866.

<u>Work Alignment:</u>

Figure 5.6 displays in a green arrow the organizational prioritization of R&D and their definition of the process as a key driver to develop the product. Furthermore, Manufacturing and Engineering act as project developers and support R&D objectives.

The mechanism to introduce all the requirements proposed in Section 3.6 is by using a team solution technique to tackle the proposed forced variables when the team reaches the relevant QFD House. For example, workshops and brainstorming sessions, before the HoQ session, would communicate and fix the strategies in the team's perception. After that, the HoQ can be deployed with the team and some of the previous conclusions can be included in the Design Requirements row. The HoQ for Thermiculite 866 defined, after brainstorming with the Technical Team, the following main conclusions:

- Operations mechanisms and technology requirements to reach high volume production of the Thermiculite 866 by 2015.

- QA needs to be linked to the Manufacturing Process from the beginning of the process development. In other words, process restrictions would force product features when required.

The major outcomes from the brainstorming were used as forced design and customer requirements. For example, the drying time was defined as process bottleneck and its forced design requirement to maximize throughput by probable increase of the Thermiculite 866 solid contents in the wet material prior spreading. This is a good example of how SAQFD promotes loops from the House III to HoQ to change product specifications when required. This early feedback is valuable to gain time and other resources during the products development.

Analysis of the Product:

The first outcome from project owners (Section 1.6) was a general marketing plan & corporate strategy for the Thermiculite 866. The plan for the Thermiculite 866 production line implementation is defined by the SOFC end user development in following years. It has been predicted that the Thermiculite 866 demand would increase 300 times for one of the SOFC major customers during the next four years. This is a major driver that defines two forced inputs for the process and production requirements in the SAQFD (Analysis of Product Figure 5.5):

- Expected high volume production line needs to be considered in the QFD process planning

- Production volume ramp-up in 2015 year must be considered in the QFD process planning & production planning

Due to the novel nature of the SOFC market, it is important to get to the market and support customers with their technical challenges by aligning strategies according to their demand requirements. The original target was to design and to implement a high volume production line to introduce the Thermiculite 866 range by 2015, but the SOFC development and experimental phases were delayed ten months. For this reason, the production line implementation would be accomplished by implementing modular equipments concept during the following years. This is an example of workforce and strategic alignment using the analysis of product to define predefined process requirements with no considerations from the HoQ in this stage.

Analysis of the Current Process:

The reader must know that the Thermiculite 866 project intends to use some of the experimental equipment to construct the future high volume production line. For this reason, most of the engineering characteristics were defined from the third house (Process Planning), and the proposed Strategic Alignment is applicable to the Thermiculite 866 project. As stated in the introduction of thesis, no technical data will be presented, and the main relationships that where defined in the HoQ are:

- Density of the Thermiculite 866 dough as a key driver of other product features such as WPUA and settings of the spreading head settings.

- The mixing settings would have a moderate impact on the WPUA and probably a weak relationship with specks presence

- The cost of the product and production capacity may be strongly affected by Drying capacity and it has a close relationship with the supply of raw material from alternative resources

- The importance of the material formulation was defined as priority 5 above WPUA and thickness

The HoQ produced sixteen design requirements and eight customer requirements (product technical requirements) and twenty-eight relationships. Considering the outcomes of the HoQ and Strategic Alignment, the diagram of the SAQFD:

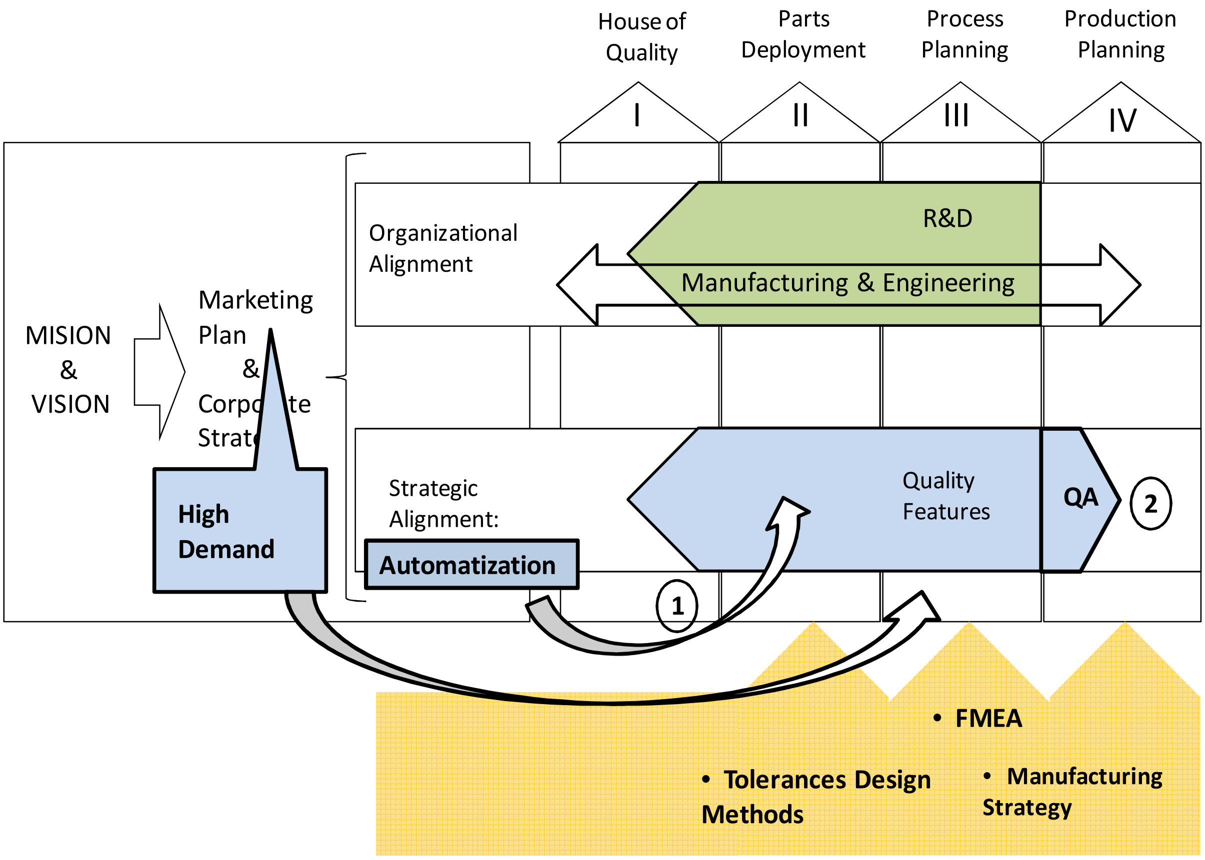


Figure 5.6: The schematic SAQD for the Thermiculite 866

<u>SAQFD for Thermiculite – Houses I, II & III:</u>

The SAQFD is especially useful for NPD, as the Thermiculite 866 project, that was not originally conceived from the HoQ. Figure 5.7, the SAQFD exercises Houses I, II and III have been put together using the format that was explained in Figure 3.2 (Section 3.6). This gives to the reader the SAQFD methodology in terms of format and how customers' requirements and product design can be aligned on the left hand side of the house.

Four methodologies to improve the Thermiculite 866 quality, cost and responsiveness are explained below.

- FMEA: The original QFD did not emphasize the implementation of the process design FMEA and it is necessary to add this analytic mechanism to the proposed SAQFD. The Flexitallic team developed a FMEA to envisage any problem in the Thermiculite 866 manufacturing process. The team envisaged minor potential variable during spreading and potential significant variation during ingredients weighing.

- Tolerances design methods: WPUA is key parameter that needs to be monitored and analyzed with statistical methodologies. The analysis of standard deviations would envisage important variables relationships in the processes and provide valuable information for QA and automation.

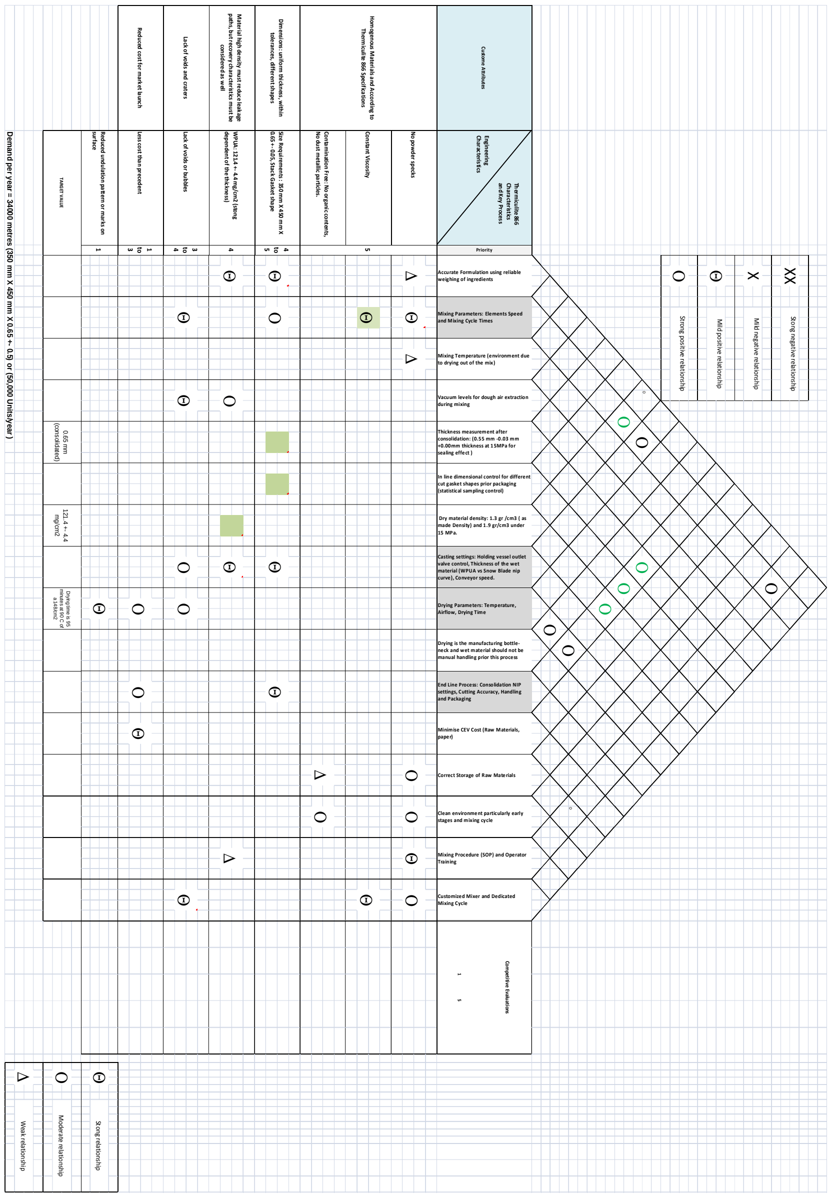
- Automation implemented at any cost: Considering the circled number one in Figure 5.6, which is a forced requirement of automation. It has been defined that automation needs to be considered for production capacity improvement and QA. The automation of the cutting and packaging system increases the capacity of the line. In addition, the control of critical parameters such as raw material weighing, mixing cycle parameters, spreading head settings, WPUA and thickness checks are important for QA. The automated system requires a centralized information system to control QA in the line.

- QA defined from process planning: This forced requirement is represented by the circled number two in Figure 5.6. The impact of this requirement on the Thermiculite 866 high volume production line is that the QA is defined according to the process limitations rather that the product features. For this reason, the Thermiculite 866 QA is based on process control rather than product checks. In fact, the process control affects the product specifications through a simple lineal relationship. The density/mass/volume equation defines the required control system loop for controlling the dough spreading process according to QA requirements.

- The Thermiculite 866 SAQFD in detail: The SAQFD process required about four months from the team definition to define most of the process planning (House III). The Thermiculite 866 project team provided the expected organizational alignment and engagement with the project. Although, its definition and official presentation was delayed because it was the first time the QFD methodology was performed at Flexitallic. Regular meeting reviews permitted to define major requirements for the project and requirements for the SAQFD.

The Strategic Alignment analysis provides a better understanding of the project requirements with stakeholders and it produces the Thermiculite 866 Implementation Plan with four hundred specific tasks to be delivered in the next two-year period. In addition, the brainstorming prior the formal HoQ delivered enough documentation to define technical requirements, and raised forced design requirements such as the change of product characteristics by increasing the solid contents to improve the line throughput. Finally, it was difficult to fully perform the Process Planning (House II) due to the unexpected outcomes from the mixing process after installing a new mixer. In fact, this issue conducted our effort to performing statistical analysis and applying tolerance design methods. The HoQ document of the SAQFD is displayed in the Figure 5.7

Figure 5.7: The SAQFD exercise for the Thermiculite 866



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5.4. Manufacturing Conceptual Design

This is section 4 in the PMP from Figure 4.3. SAQFD and the Batch Flow Comparative Matrix are core components to develop the conceptual design of the Thermiculite 866 manufacturing system from the current laboratory scale process. This means that all research, process and product development done in Flexitallic in the last seven years will be considered. However, new technical approaches and changes of management will be introduced in the project in order to design a suitable line according to Flexitallic requirements. The analysis conducted in Sections 5.2 and the commissioning of new equipment lead to two major concerns: mixing/casting process as a quality cornerstone and drying process as a major manufacturing bottleneck. Considering that the Thermiculite project needs to be on-line by 2015, this thesis covers the first six stages of quality critical process such as: mixing and casting. In fact, this document only covers the first four stages of less urgent processes such as drying (due to reduced demand). As explained in previous sections, the project and management approach proposed in this thesis states a basis for line design and from this first point each equipment and sub-process would go through the conceptual design, detail design, implementation and continuous improvement cycle.

In addition, the following bullet points from SAQFD are important observations to define the guidelines in the definition, detailed design and implementation stages:

- The DEMAND analysis (80,000 thousand parts per year in 2015 in the UK) has defined that the process requires and improved drying process (current manufacturing bottleneck) and automation of the packaging process

- THE PRODUCT and PROCESS are favourable to promote flow concepts and achieve the required high volume production levels. The Thermiculite

866 manufacturing can be summarized as the accurate spreading of wet material and posterior quick drying of this material. In fact, only more waste would be obtained when adding more intermediate processes.

The Conceptual Design of the production line and the detailed design of specific equipments are explained in the following sections. The detailed design of the drying solution and the packaging system are planned to be finished by May 2012, and these would lead commissioning and implementation by the third quarter of 2012. Finally, the official launch of the high volume production line is planned to be by the end of 2012.

5.5. Plant Layout and General Conceptual Design Approach

The SAQFD developed to support the implementation of the entire Thermiculite 866 production line, but its outcomes are focused in the Conceptual Design. In addition, the definition of the future target cycle time and value stream has been defined by the forecasted demand in the next five years. As explained above, 88% of the drying capacity would be used by 2015. The design of a modular drying solution and the "four conveyor" casting strategy will cope with the expected demand increase in the next years. The four conveyor casting strategy intends to start extracting moisture by spreading wet material just after mixing. Furthermore, considering the relative low drying temperature of 90 ^{O}C, a drying time of less than 150 minutes can be achieved for Thermiculite 866 dough of 29.0 % solids. The aligned exfoliated vermiculite acts as an inorganic binder to bind all ingredients. As a result any microscopic paths that exist perpendicularly through the formed sheet have a very low degree of permeability and thus it is difficult for water vapour molecules to travel across them. This means that drying time cannot be reduced by increasing temperature because it causes blistering on the material surface. The "four conveyor" strategy intends to increase drying capacity by increasing the drying area with a 90 ^{O}C continuous drying solution supported by zoned ovens. Finally, the strategy and general budget expenditure plan for the implementation of the Thermiculite 866 Equipment-Paced Line Flow during the next four years has been defined.

The proposed manufacturing strategy has been agreed with project owners and process developers and the final line layout would be:

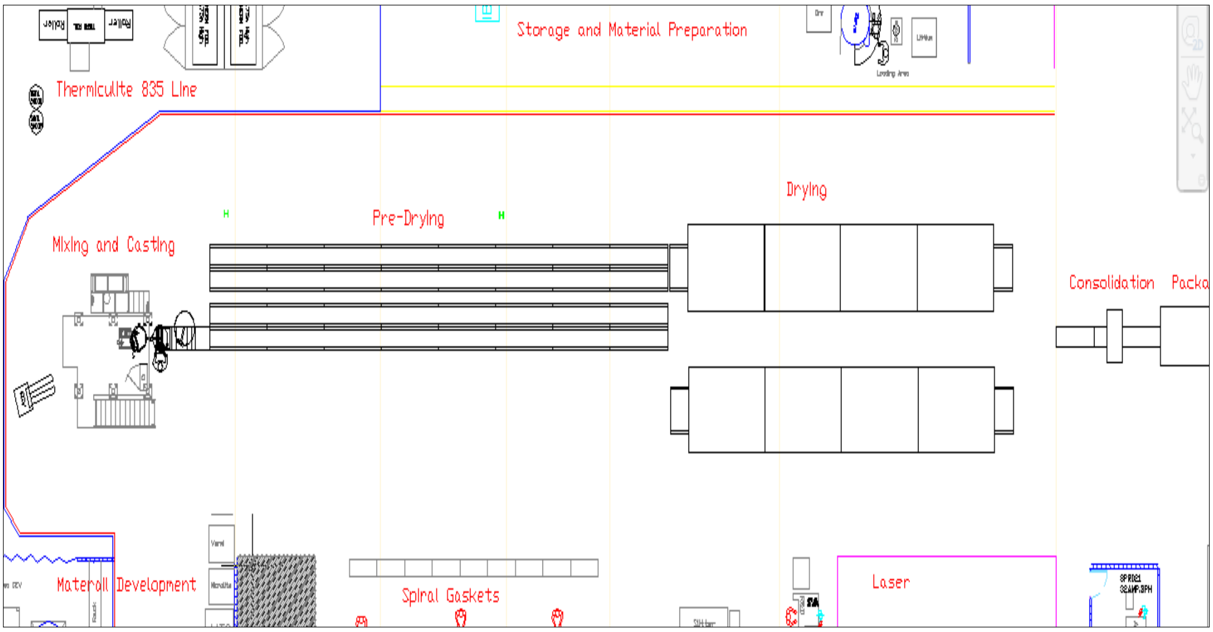

Figure 5.8: Project Thermiculite 866 Plant for Start of Production

The Equipment-Paced Line Flow is the best manufacturing system for the future Thermiculite 866 demand and achieves the cost, quality, performance, delivery, and flexibility requirements. The first stage of its implementation of one conveyor (pre-drying) and tracking system and the first drying module would cost in excess of £100k according to quotations from two companies in September 2010.

The conceptual design and trials suggest modular design to facilitate future capacity expansion and the application of drying zone concept to reduce moisture to 6%. In fact, the future Thermiculite 866 flow line will reach high volumes by using four parallel conveyors aligned to a pair of 90^{O}C continuous zoned ovens. The temperatures would be raised to 90^{o}C in the middle section from the first section and would be dropped back to room temperature at the end. Finally, the end line will cut and package cut rectangles of shaped gaskets.

5.6. Drying Trials: Cooperating with the Conceptual Design

The technical information included in this section is part of the Drying Trial Report by Hoyes (2009) at Flexitallic Ltd. These trials, that aim to understand the Thermiculite 866 drying characteristics, were conducted before the conceptual design agreed in 2010. This is a partial achievement in section 4.2: conceptual design & trials in drying part of the PMP.

The production line arrangement can be achieved if the current drying time is reduced and Hoyes (2009) raised this point by saying “Currently a 2mm (wet thickness) grade is produced in a batch oven in approximately 10 hours. Lab tests have been carried out by Flexitallic which show that a significant reduction in dwell time is possible”. Unfortunately, no drying parameters can be exposed in this thesis due to information sensitivity.

During trials the temperature was changed to define the limit where blistering is obtained on the sample surface. The nature of the micro-structure of the material does not permit easy water transfer from inside the sheet because exfoliated vermiculite creates an intricate path for evaporated moisture. After testing different temperatures and airflow conditions in specific times, temperature and air speed at specific material thickness. In addition, different trials defined temperature limits for the product.

Considering the wet sample that would accomplish the required thickness for SOFCs, it was found that wet samples can be dried in a dwell time of ~4 hours, which is not encouraging. For this reason, further trials will be conducted in February

2012 to reduce drying times by changing temperature and air-flow (volumes and directions). Furthermore, the four-conveyor system described in Section 5.4 would pre-dry the wet material on the four conveyor system prior to getting it into the oven. This drying solution would act as a continuous zoned oven that starts with a 20-22 C and would end in a 80-90 ^{O}C chamber.

5.7. Mixing: Detail Design and Cycle Improvement

The mixer conceptual design was defined by the product and process development team at Flexitallic and the support and expertise of a local company. This is a partial achievement in section 4.2: Conceptual Design & Trials and full example of Section 7 in Figure 4.3. Several trial sessions were conducted at the supplier site to define mixer features and main mixing cycle sequence and times. Continuous communication and brainstorming with the contractor permitted to develop drawings and technical specification for internal approval at Flexitallic: Quality, Operations, and Product Development Departments. The mixing system installed at Flexitallic is an automatic system designed for the mixing and removal of air from Thermiculite 866 dough. All operational control functions are implemented from an Operator Interface panel located in the immediate vicinity of the mixing and holding vessels. The Operator Interface screens provide control functionality and status information throughout the automatic mixing process. There are some functionalities to undertake maintenance tasks through the provision of manual operations for system devices such as valves, motors etc.

The mixer detailed design was approved in four stages, four gates were defined before any equipment was approved and CAD drawings were released for commissioning. These gates are: concept development and trials, system level design and detail design as explained in Section 3.7. The intention is to engage the

Technical Group, Operations and Compliance in the equipment selection and to promote communication, cooperation and 'risk sharing' during commissioning and purchasing. In fact, several issues were addressed when the equipment was installed at Flexitallic site. In the beginning, some assumptions such as that the blender had the capability of 'over-mixing' the dough with negative consequences for the viscosity. This effect reduces the viscosity outside of the range that can be controlled satisfactorily during spreading. Different options were considered to overcome this issue, although the problem persisted for at least ten trials. There were some alternatives such as not using the element assumed to cause the over mixing, or reducing the particles of one of the filler materials. The WPUA, which is the mass of a specific unit area of a dry Thermiculite sheet, was difficult to control in order to achieve customers' requirements. The required specified WPUA for one of the major customer was only possible to achieve by the laboratory mixing cycle. This mixing issue was the result of poor structured trials prior to commissioning and equipment malfunction.

Considering that Thermiculite raw materials and the optimised mixing cycle are the core part of the process, in it is necessary to broadly explain the mixing cycle. First, liquid material is poured into the mixer to a specific level. Then, powders are carefully added when the mixer is running. The mixing components in the mixer create a good vortex whilst the powders are added, as the intention for the vortex to swallow them. A degasification cycle with a continuous three dimensional action is activated after several loading stages. In this stage is possible to see the air bubbles being brought to the surface due to the three-dimensional mixing action and then bursting as a result of the vacuum. Then the mix is cast using sets of blades of up to 7mm in thicknesses. This material is dried at room temperature conditions or forced-dried with electrical heaters. The material is weighed and tested to observe its sealing characteristics.

The mixing cycle proved to be unsatisfactory with WPUA discrepancies due to lack of flow control during casting. Although, some of the new features where seen as a “good thing”, there were far more harm consequences to the product features that would require further research and approbation of change in composition from important customers.

At this point, several desperate options were adopted but those were merely short-term solutions. For this reason, a structured numerical analysis of previous trials was required. When a process is being developed or has been identified as needing optimization, a technique called Design of Experiments (DOE) is utilized. If the process is simple and involves only one or two inputs, simple experimentation is usually sufficient (Raisinghani et al. 2005). When the process is more complex, involving several inputs that may have interactions, a DOE is required to explore the relationship of the output to the inputs. An example of this is a complex manufacturing process that has inputs such as temperature, pressure, several gas flows, process speed, etc. where each can be changed independently. The outputs of a process may be dimensions, thickness, resistance of a material, or WPUA as is the case of the mixing improvement.

Considering the random variation of parameters during first trials the traditional experimental procedure of taking one factor at a time most times will not be successful due to the factor-to-factor interaction which was ignored. The DOE technique explores the operational space for all the inputs, producing results that could show non-linearity and interaction. The output of a well-defined DOE is a mathematical process model that predicts the response of all the output variables for any combination of inputs. For example, a DOE would permit to understand the impact on viscosity by changing mixing parameters such as speed. Furthermore, the rigorous treatment of a manufacturing process, including process modelling, is integral to Six Sigma methodology and this approach permit to develop QA. Each factors' significance is quantified using analysis of variance and the resulting model is used not only to optimize the process, but to trouble shoot the process when deviations occur as it was happening in the WPUA samples. Consequently, the analysis of previous trials would be based on finding trends in the WPUA standard deviation. This approach solved most of the interdependency between mixing parameters and product features. There are more than fifty different variables that can be introduced into the mixing cycle and this number might be multiplied by the possibility of blade settings during casting. This gives to the reader an idea of the challenge the team had to face in order to obtain a good mixing cycle using the new and already in-site expensive mixer. In addition, to define the QA for the production line is required to understand more specific product features using an analytical approach and not tested theoretical assumptions. For this reason, a “mixing energy” analysis based on used parameter and Weigh per Unit Area (WPUA) checks was developed by the author of this thesis.

Although the mixer was designed for a 150L full capacity, it was found that the optimum batch size is between 50L and 100L. Considering this development it is possible to fix one of the variables, which is the batch size. The utilization of mixing energy as a parameter for analysis has been used before. For example, the first studies of power consumption date back to 1934. Using dimensional analysis, Rushton developed the power number Np:

$$N_p = \frac{P}{\rho N^3 D^5} \qquad \textit{Equation (4.1)}$$

Where P is the power required by the impeller, p is the fluid density, N is the rotating speed of the impeller in rotations per second and D is the diameter of the impeller. The power is usually calculated from measurement of the torque and the shaft speed (Rushton, 1950). This approach highlights the direct action of the power introduced in the mixing into the mixing, and the opposite action of the fluid density.

5.8. Analysis of the Power/Work Produced During Mixing

This analysis aims to reveal the impact and relationship between mixing parameters, casting variables and Weigh Per Unit Area (WPUA) results in samples along the 25m length. The analysis uses the principle defined by Rushton (1950) and the WPUA standard deviation. In fact, this is the only common parameter to compare the performance of different mixes and castings using a statistical analysis for DOE. The sampling methodology adopted by Flexitallic suggests taking five samples every 1.5 meters along the 25 meter length. Those dry samples are standard 2x2 inch squares and their weight would fluctuate depending on their thickness. Almost 2000 samples have been gathered and classified for the analysis explained as follows. The most important parameters were defined considering the power number proposed by Rushton (1950): mixing time and speed of the blender and anchor. This leads to a simplification of the original Rushton number by using a general energy conservation concept or the work produced by the mixer during a period of time.

If a force is allowed to act through a distance, it is doing mechanical work. Similarly, if torque is allowed to act through a rotational distance, it is doing work. The equation for rotation of a fixed axis through the centre of mass.

$$W = \int_{\theta 1}^{\theta 2} \tau d\theta \qquad \textit{Equation (4.2)}$$

If τ is constant and equal to:

$\tau = 9550\ P_{kW} / n_r$

Where:

τ = torque or moment (N.m)

P_{kW} = rated power (kW)

n_r = rated rotational speed (rpm)

* The 9550 comes from $60 * 1000/2\pi$

Considering the Lenze 32699 External EN60034 electric motors in the mixer with 50Hz electricity frequency.

Torque Agitator (Motor MDE MAXX 090-32) = 9550 x 1.50 kW / 38.3 rpm = 374.02 N.m

Torque Blender (Motor MDE MAXX 090-32CIC) = 9550 x 0.75 kW / 275.2 rpm = 26.03 N.m

Which is similar to the suggested the electric motor manufacturer: 355 N.m for the Agitator and 25N.m for the Blender at 50 Hz

Then

$\tau a = 355\ \mathrm{n.m}\ (\text{Torque Agitator})$

$\tau b = 25\ \mathrm{n.m}\ (\text{Torque Blender})$

Considering the work and torque integral:

$$W = \int_{\theta 1}^{\theta 2} \tau d\theta = (\Delta\tau\ \mathrm{mix})(\Delta\theta\ \mathrm{mix}) = \tau\mathrm{mix}\ (\theta 2 - \theta 1)$$

Where

$$\theta 1 = 0$$

$\theta a = angle\ of\ displacement\ during\ talc\ addition$

$\theta m = angle\ of\ displacement\ during\ mixing$

$\theta v = angle\ of\ displacement\ during\ vacuum\ stage$

$\theta 2 = \theta add + \theta mix + \theta vacuum$

Then

$$W = \tau a(\theta a + \theta m + \theta v) + \tau b(\theta a + \theta m + \theta v)$$

$$W = \tau a\ (rpma1 * ta1 + rpmam * tam + rpmav * tav) + \tau b(rpmb1 * tb1 + rpmbm * tbm + rpmbv * tbv)$$

Where:

$rpma1 = revolutions\ per\ minute\ agitator\ during\ talc\ addition$

$rpmam = revolutions\ per\ minute\ agitator\ during\ mixing$

$rpmva = revolutions\ per\ minute\ agitator\ during\ vacuum\ stage$

$ta1 = operation\ time\ of\ agitator\ during\ talc\ addition$

$tam = operation\ time\ of\ agitator\ during\ mixing\ stage$

$tav = operation\ time\ of\ agitator\ during\ vacuum\ stage$

$rpmb1 = revolutions\ per\ minute\ of\ t\hbar e\ blender\ during\ talc\ addition$

$rpmbm = revolutions\ per\ minute\ of\ t\hbar e\ blender\ during\ mixing\ stage$

$rpmbv = revolutions\ per\ minute\ of\ t\hbar e\ blender\ during\ vacuum\ stage$

$tb1 = operation\ time\ of\ blender\ during\ talc\ addition$

$tbm = operation\ time\ of\ blender\ during\ mixing\ stage$

$tbv = operation\ time\ of\ blender\ during\ vacuum\ stage$

If we consider that the mixing elements in the mixer at Flexitallic are managed using percentages of electrical power, the Accumulated Mixing Energy or Total Work in Kilo Joules is:

$$W = 76953.4 * (\%a1 * ta1 + \% am * tam + \% av * tav) + 38905.6 * (\% b1 * tb1 + \% bm * tbm + \% bv * tbv) \quad \textit{Equation (4.3)}$$

Where

$\%a1 = agitator\ power\ usage\ \ during\ talc\ addition\ in\ \%$

$\%am = agitator\ power\ usage\ \ during\ mixing\ in\ \%$

$\%av = agitator\ power\ usage\ \ during\ vacuum\ in\ \%$

$\%b1 = blender\ power\ usage\ \ during\ talc\ addition\ in\ \%$

$\%bm = blender\ power\ usage\ \ during\ mixing\ in\ \%$

$\%bv = blender\ power\ usage\ \ during\ vacuum\ in\ \%$

The most encouraging findings using this concept are in the following section:

Our perception about the mixer inaccuracy was magnified by the change of mixing and casting parameters when the team tried to obtain the WPUA and blade settings curve for new mixer. Following some conclusions from the analysis.

- Conclusion 1: The lab mixes obtained 42% higher performance compared with the new mixer in terms of WPUA standard deviation. Furthermore, the lab mixes proved to be only 29% more effective targeting the required WPUA: 121.4 +- 4.4 mg/cm2.

- Conclusion 2: The standard deviation increases linearly in response to Work or Energy introduced during the mix without considering batch size. Although, the standard deviation tends to reduce if the analysis is performed in a per kilogram scale. These different trends might be attributed to poor incorporation of talc during mixing due to reduced load time. In fact, the energy per kilogram supports this conclusion if we see Figure 5.9. Accumulated Mixing Energy per Kilogram VS Standard Deviation compares three major variables: batch size, accumulated Mixing Work and blade settings. This trend needs to be considered to define a consistent mixing cycle. It seems that by adding energy in the mix the WPUA dispersion is reduced. For example, the lowest standard deviation of 0.70 was obtained by adding 4213 KJ/Kg during the mixing, which is the highest Work per Kg during our trials.

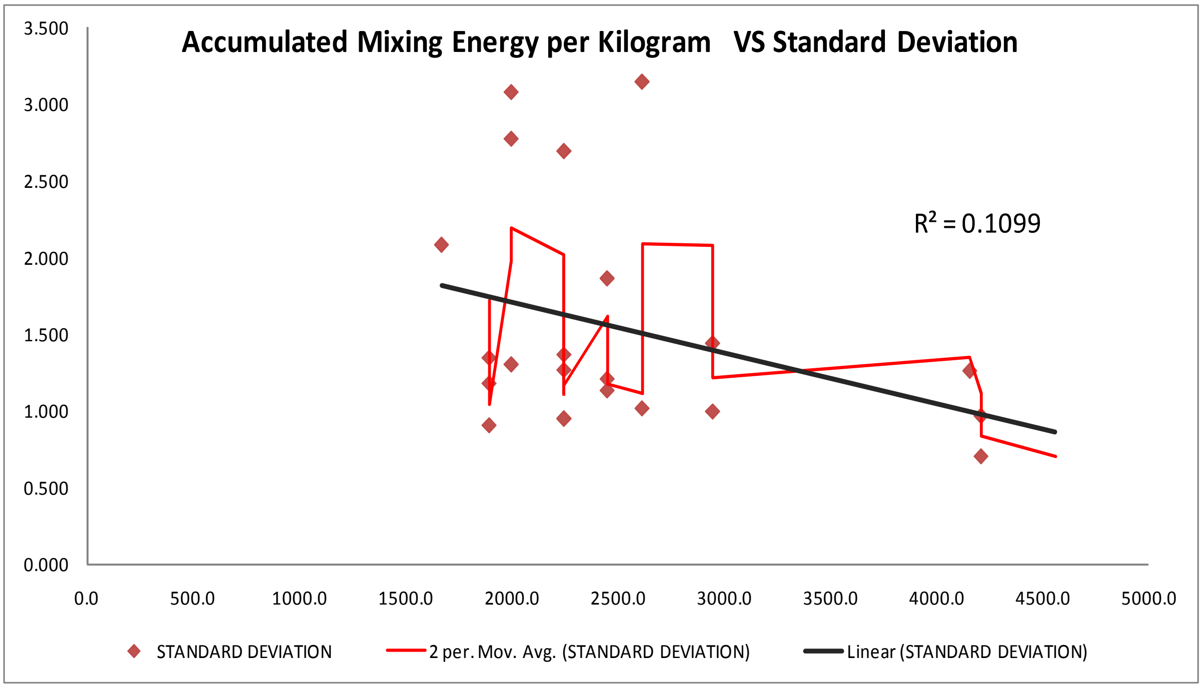

Figure 5.9: Accumulated Mixing Energy per Kilogram VS Standard Deviation

Thus, this seems to be a “noisy” result considering the spread of standard distribution. For this reason, the analysis was restricted to a smaller population in the range of a specific blade setting. This analysis demonstrated that the clay nature of Thermiculite material restricted its controllable flow to specific blade settings. This brought in to scene a window of accumulated mixing energy where the dough would behave in the way we predict. That window was defined between 1998 KJ/Kg and 2450 KJ/Kg for 3.6 mm to 3.9 mm.

Using these energy limits, Equation 4.3 was set to a value of 2130 KJ/Kg and an optimized mixing cycle was defined. The new mixing cycle incorporates some fixed times for degasification and powders loading. After running a new cycle for 10 trials, some excellent results were obtained. The WPUA was controlled under a limit that would permit to accomplish not only customer requirements but also the initial point for future improvements to reach Six Sigma levels. The Figure 5.10 shows the achievement of the new mixing cycle by comparing the WPUA standard deviation of previous trials (pink bars) against the new results after implementing the improved mixing cycle (orange bars).

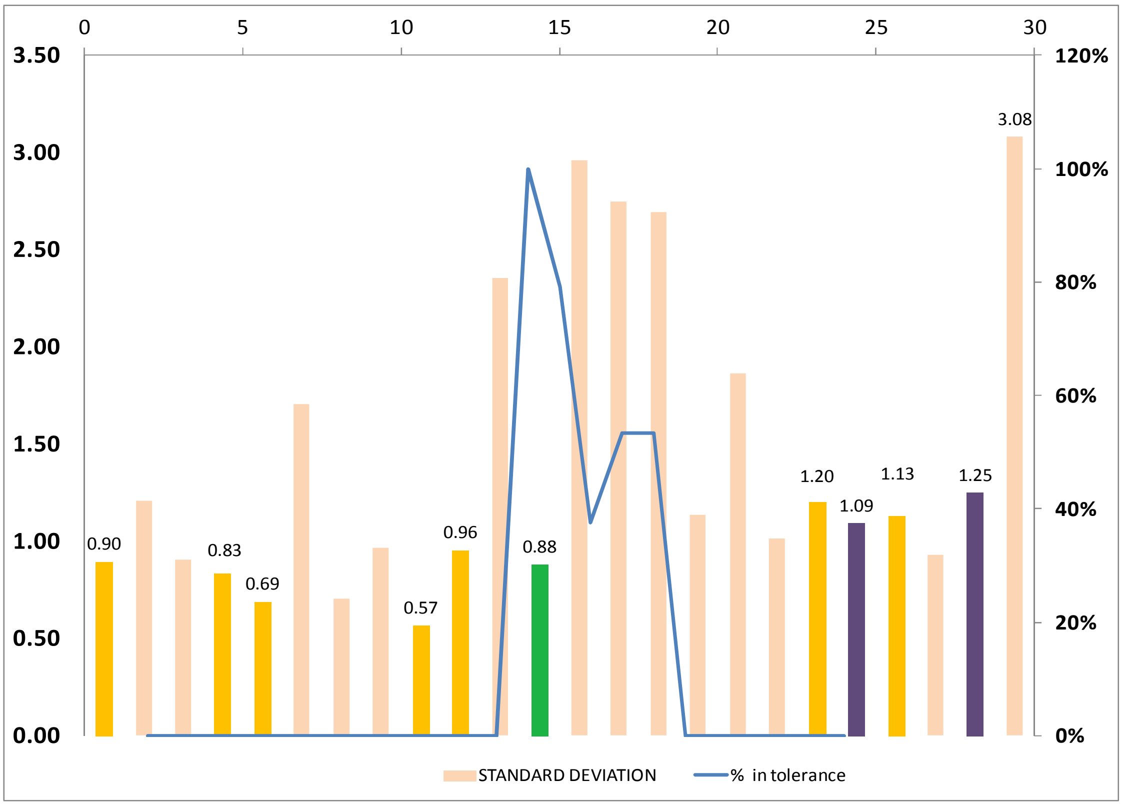

Figure 5.10: Standard Deviation and WPUA

The graph shows the average standard deviation of 0.90 which is considerably better when compared to the 3 standard deviations of the highest deviation in the not numbered bars (prior the mixing cycle improvement).

5.9. Tape Casting: Looking for alternatives to support Quality Assurance and Improvement

This process has been in situ for about 5 years and now is achieving the improvement stage (Section 7 in Figure 4.3). The mixing cycle provides “homogeneous” mixes by controlling the speed and time of the anchor and blender mixing elements used in the cycle. The improved mixing cycle intends to “control” the disassembly of the vermiculite stacking and/or reduction of the links in its clay structure when it is wet. In fact, these two parameters might be responsible of viscosity change when the Thermiculite dough has been mixed extensively out of the “energy safe window defined in the previous section”. One of the product developers, John (2011), mentioned that the wet mix should be considered as a Thixotropy substance. Furthermore, Bond (2011), Vice-President (VP) of technology at Flexitallic, suggested that vermiculite behaves similarly to clays, which means that in concentrated vermiculite suspension a three dimensional solid gel structure is formed. Although the details of the Thermiculite 866 nanocomposite structure has not been explored, the analysis of the Total Work during mixing is a good mechanism to extrapolate the effects of mixing in the vermiculite-talc-water system and the result in the dry solid structure.

Currently, the 122 kg batch mixing cycle provide a relievable WPUA variation of 0.9 average standard deviation. The robust mixing cycle proposed in Section 5.7 warranty two key parameters for the Thermiculite 866 process: homogeneous and controllable mix for spreading. In fact, in this point, the mixing process must be considered only as a raw material supplier where the key parameters are:

- Density: Controlled by material composition and powder addition

- Homogeneity and Viscosity: Obtained by correct incorporation of materials in the proposed mixing cycle

5.10. Spreading Head and Conveyor System

Considering the previous analysis, it is possible to analyze the next process after mixing which is spreading or casting.

The forming head is a two blade system where the second blade or scraper is to correct defects left by the first blade reservoir. The system provides wet material to a 25 meter conveyor that uses a carrier of the mix under the blades and into the drying system (Hoyes, 2009). The following principles are used for designing the best casting control system and warranty a uniform WPUA along the 25m length:

a) The mass flow remains constant through the casting process. The control of the buffer level in the first blade reservoir is only required to start-up casting.

b) The possible change in mass flow might be produced by a non-homogenous and/or low viscous mix, which is controlled with the mixing cycle and checked with the in line densimeter.

The current spreading process relies on three major devices:

- Fishtail: the main function of this element is to spread Thermiculite 866 dough into the first blade reservoir. The fishtail design should provide good material spreading after material flows out the vessel outlet. In addition, it should reduce exposition of the dough to air in order to avoid aeration. There is a concern that air has been dragged in when the dough is poured in the first blade reservoir.

- First blade reservoir or low-pressure extrusion device: Two metal blocks on each side of the first blades form a compartment, which is a buffer for the mix carrier. The level of the mix in the reservoir defines the pressure under the blade and consequently the flow of material onto the carrier. This “low pressure extrusion” effect does not have any impact in the alignment of vermiculite plates as wrongly assumed (if there is any alignment before drying). In fact, the movement of the carrier under the dough might create an extremely turbulent flow when interacts with the wave created by the pair of blades.

- Device 2: this device defines the final thickness across the wet length. The main function of this device is to warranty the wet material “thickness”. For this reason, it should not be considered to add any barriers at the sides of this blade because it would create another reservoir and consequently differential pressures under the blade. This device might be eliminated in the future if the first reservoir and low-pressure extrusion reach the required WPUA distribution across lengths. In fact, we should try to reduce the scraper correction by reducing the “size of the wave” to a few millimetres.

5.11. The Control System for The Spreading Process

This section shows the continuous improvement cycle proposed by Item 7 from Figure 4.3 as part of the product development. As first proposed, it is quite valid to implement a feedback system based on sensors to control the scraper wave. This would replicate the current methodology to control flow using blade settings and appreciation, but this is not the best way to control mass flow. In fact, there are couple of issues such as interface between fishtail, reservoir and scraper. This issue would be time demanding when trying to understand the links between variables such as mix height in the first blade reservoir, wave length against the scraper, etc. In contrast, we should adopt a quality "downstream" approach where we bring standard product from the previous process. This is possible if we obtain "standard" dough, in terms of density and viscosity from the mixing cycle. So far, it has been obtained encouraging results with the 122kg mix cycle, so we can move on to the next process: spreading in the COMAC line.

First, going back to product requirements we need to where values have been replaced by letters due to senility with such information. :

1) WPUA: BBB mg / cm2 + / - C.C mg / cm2

2) Y.YY mm -V.VV mm +0.00mm thickness at 15MPa.

The WPUA concept can be linked to density by:

$$\rho_{wet} = \frac{m_{wet}}{V} = \frac{m_{wet}}{A_{spread} \times t_{blade}} \cong (factor)\frac{m_{dry}}{A_{dry} \times t_{dry}} = \frac{WPUA_{dry}}{t_{dry}}$$

Or

$$\frac{m_{wet}}{A_{spread} \times t_{blade}} \cong \frac{1}{(factor)} \times \frac{WPUA_{dry}}{t_{dry}} \qquad \textit{Equation (4.4)}$$

Where:

ρ_{wet} = density of the HTS-talc mix

m_{wet} = mass of the HTS-talc mix

V = volume

A_{spread} = 45cm x 2500cm = 112500 cm2 (area Thermiculite 866 spread in casting)

t_{blade} = wet material thickness defined by the scraper or snow blade setting of 3.75 mm

m_{dry} = mass of the dry Thermiculite 866

A_{dry} = area of the dry Thermiculite 866

t_{dry} = thickness of the dry Thermiculite 866 that according to previous compression curve test it should be within 0.88 – 0.94 mm

$WPUA_{dry}$ = requirement of BBB mg / cm2 + / - C.C mg / cm2 (Customer A)

$(factor)$ = this factor represent the ratio between water transferred during drying and change in thickness. Considering that $A_{spread} = A_{dry}$ then:

$$(factor) = f = \frac{m_{wet} \times t_{dry}}{m_{dry} \times t_{blade}} \qquad \text{Equation (4.5)}$$

Where for a for Thermiculite 866 dough of 29.0 % solids, $\mathrm{t_{dry}} = 0.91\mathrm{mm}$ and $\mathrm{t_{blade}} = 3.75\mathrm{mm}$

$$f = \frac{100 \times 0.91}{29 \times 3.75}$$

$$f = 0.84$$

Then for Customer A requirement the equation is:

$$\frac{m_{wet}}{A_{spread}} \cong \frac{1}{0.84} \times \frac{121.4}{0.091} \times 0.375$$

Or

$$m_{wet} \cong 595.6 \frac{\mathrm{mg}}{\mathrm{cm2}} \times 112500 cm2$$

Then

$$m_{wet}\, per\ second \cong 89.3\ \mathrm{gr/\,sec} = 321.5\ \mathrm{Kg/Hour}$$

This is the required Thermiculite 866 mass flow to produce 25 meters of Thermiculite at specific meters/minute conveyor speed, and it can be adjusted according to thickness, WPUA, or other requirements.

The reservoir and low pressure extrusion device can provide this mass flow with a Constant Flow Valve (CFV). The CFV would operate under variable differential pressures between the holding vessel outlet and the Fishtail. This Controls the casting process prior the Fishtail which reduce variability and control requirements. The required level of the mix in the reservoir would be obtained by reducing the nip under the first blade during few second when starting casting. In the future, this might be semi-automated by sensing the mix level using and improved fishtail. In conclusion, this move from vision-automated feedback to controlled flow will result in a simpler and potentially cheaper control for the spreading process. Finally, the proposed system supports the Thermiculite downstream QA for the production line.

5.12. Consolidation and Packaging: Conceptual Design

This section is the right example for conceptual design and it is part of product and process development in Figure 4.3. Every figure and strategic information has been replaced with capital letters such as X in order to keep the context in the explanations. Those characters do not have any particular meaning in the project they just represent classified information.

The Thermiculite 866 sheet has a density of X gm / cm3 before rolling and it can easily be compressed to produce a sheet material which a density of about M gm / cm3. Both forms are available from stock in thicknesses of 0.3, 0.5 and 0.7 mm with other thicknesses available on special request. The material is currently available in lengths of up to a metre at a width of up to 0.45 m (Flexitallic Group, 2010). This information in the current product brochure shows the availability of standard material that has been cold rolled after drying to 5% moisture content. The accuracy of the Thermiculite 866 sheets for SOFCs has been set to be consolidated to Q.QQ mm +/- P.PP mm. Once the nip had been set, the thickness of the material is checked in a 4% frequency. Several trials have been undertaken to define the correct spreading of material during rolling the sheets, and it has been concluded that there is a maximum spreading of 2.4%, and minimum of 1.7% with rectangle samples.

The Thermiculite 866 end line will use a Flexible Manufacturing System (FMS) considering that this system is suitable for medium and high production volumes. In addition, the proposed solution needs to consider different gaskets shapes and other Thermiculite range products. For this reason, the equipment will employ a Reconfigurable Manufacturing System (RMS) philosophy through reconfigurable equipment to warranty flexibility of production. The RMS capability considers rapid changeover, rapid introduction of new products and unattended operation Xing (2008).

The proposed systematic control will be based on laser thickness measurements, which would warranty 100% measurement post consolidation. The complexity of the rolling process relies on handling of the dry material prior the process and after consolidation. Furthermore, cutting and packaging as seen in Section 5.2 would be ideally at least semi-automated.

The proposed sequence of processes would be:

Sampling WPUA, Peeling, Consolidation, Visual Inspection and Thickness Check, Cutting, (WPUA check), Packaging and Labelling.

The proposed process is a consequence of how things have been done over the last seven years. The approach adopted to reduce processes and warranty quality is by reducing double checks and arrange them using new technology.

5.13. Quality Assurance: Quality Checks and Measurement

Quality Assurance needs to be linked to the sequence of processes and outcomes of the SAQFD in Section 5.3 which also defined the conceptual design Section 5.4. In order to apply QA policies on shop floor, the strategy was to introduce Lean Manufacturing tools that support quality management. For example, 5Ss, Six Sigma, Problem Solving Diagrams, Standardized Operation Sheets, FMEA, etc. In general these tools reduce the process variation and promote continuous improvement and prepare operators for managing a high volume process. The master plan which has been produced 18% of the 150 tasks Feb/2011 is included in Appendix 3.

For specialised products such as Thermiculite 866, the company develops the Quality Standards as part of the product and process development, which was based on the SAQFD. The main customer defined the Thermiculite 866 critical dimensions such as thickness and bulk WPUA required by the SOFC industry. In addition, the gasket needs to provide great sealing properties whilst supporting extreme temperatures and corrosive environments. Finally, surface condition is stated as part of the specification: the rectangles must be free from all surface defects, scratches and inclusions with a consistent smooth and glossy surface.

The SAQFD houses shown in Figure 5.7 have product specifications and relationships with processes:

- Thickness: Q.QQ mm +/- P.PP mm (consolidated)
- Weigh per unit area: BBB mg / cm2 + / - C.C mg / cm2
- Sheets Size Requirements: H mm X U mm X P mm

The relationship of this Thermiculite 866 characteristics and the manufacturing process were defined by detailed analysis of the mixing and casting processes. This analysis in Section 5.7.1 suggests providing homogenous dough by using an optimised mixing cycle based on the analysis of energy/Kg during mixing. Consequently, the first quality check would be an in line density measurement in the mixer bottom outlet. The second important parameter: WPUA would be achieved by a Coriolis meter and a control valve that would supply constant mass flow on the dough carrier. Implementing a continuous weight system for the dough is not practical and the in line density measurement provides a direct sense of WPUA through the density = WPUA/thickness formula. For this reason, the WPUA will be monitored after drying the material.

Finally, Flexitallic use the ISO 9000 as main frame of its quality system and has aligned affords to accomplish their customer requirements. For example, one of the major Thermiculite 866 customers uses the British Standards (BS) in their Quality Management System, so Flexitallic has aligned quality checks to the ISO system requirements. In fact, the Thermiculite 866 production line inspection procedures follow the requirements stated in the AQL Inspection Level II Normal Inspection RE BS6001-1:1999. The standard states that initial Sample Inspection Report needs to be done at least to 4% of material in a inspection level II (two) according to BS6001-1:1999. In addition, a Certificate of Conformance to CPL specification is required with all deliveries and these confirm conformance to specification as per the AQL standard and liable re warranty from Flexitallic Ltd.

5.14. Quality Assurance and Process Control for The Production Line

The Thermiculite 866 process requires solid QA due to characteristics of the raw material products and SOFC standards, and this section is the conceptual design number 4 in the Figure 4.3. Load cells and scales warranty the correct amount of material in the mixer which is important for material control flow of material into casting process using a Coriolis flow meter and a control flow valve. This semi-automated spreading process would be supported by an in line solid measurement device. This constitutes the second important quality check to continue the process prior casting. Then, once material has been spread under the blades and transported to the oven no intrusive measurement would be required. After drying there might be a set of checks that can be performed prior to packaging. The first parameter to be measured is the WPUA because this is a major feature that warranty sealing characteristics.

The QA would be supported by continuous thickness measurement using two, opposing laser displacement sensors that would be synchronised to obtain distance samples at exactly the same time. Finally, the process would be supported form statistical sampling from material already packed at the end of the line.

In addition, WPUA can be obtained individually by weighing the packaging case when it has been loaded with cut gaskets or standard rectangles. Each returnable case would be identified with batch number and weight prior unloading on to conveyor. This last quality check would define the acceptability of the shipment when the weight recorder of the 97 units is according to tolerances of 4%. Using the continuous thickness check and packaging check system the product will be within the limits of WPUA, thickness, and quantity per case. In addition, previous measurements such as load cells and in line solid measurement would warranty composition and homogeneity of the Thermiculite 866 gasket.

The system described above constitutes the QA system which accomplished the aims of the projects in terms of quality and high volume production.

5.15. Continuous Improvement Cycle

Finally, as part of the proposed project management in Section 4.4, a continuous improvement process is required after implementation. Suggested tasks specified in the Thermiculite 866 Master Plan (Appendix 3) promote employee engage with continuous improvement to produce improvement in quality, productivity, costs, etc. Almost all organisations that run suggestion schemes hope to achieve staff involvement and reward this with recognition (Knowledge Transfer Partnerships, 2009).

Recognition is the key issue that produces substantial success in suggestions schemes. This important continuous improvement tool has delivered important outcomes to different companies. The suggestions scheme would be classified as intangibles such as improvement of H&S, quality of the product, better working environment, etc. In addition, the outcome of the suggestion might be more tangible such as elimination of waste or overproduction, reduction of movement, etc. Every suggestion should go through a systematic validation process to warranty that its implementation and maintenance. Each department would be aware of the suggestions that have been implemented in a specific product or process. Finally, probably the most important aspect, the person or team that implemented the improvement should be recognised for the effort and impact in the company's improvement.

At Flexitallic, the quality system has not been "updated" by this valuable stream of knowledge and fresh ideas. In fact, the employees do not consider that their point of views and thoughts are important in the product quality improvement, which was contradicted by the participation of shop floor in the process development. Every suggestion would be part of the "people involvement" category in a structured business plan. This concept introduced for the first time by the Toyota Production System engages each employee within the company's values. In order to cascade the information and register the suggestion a simple 'suggestion form' would be made available on the shop floor.

Moreover, continuous improvement is one of the most used phrases in the manufacturing environment. Although, it has been treated as a hypothetical term that most of the times cannot be seen materialized in everyday jobs on the shop floor. Although, Suzaki's 1987 suggested concept of Lean implementation and continuous improvement require 90% of common sense and follow a simple sequence of activities: simplify, combine and eliminate to visually improvements in the business. From project management point of view, understanding stakeholder needs should be the first step to define any future improvement, which is entitle to middle and top managerial levels in the organization. Additionally, more operational levels would warranty customer satisfaction through operational continuous improvement. The best way for assessing a business is by auditing gaps between the current situation and company's vision. After performing a quick audit to asset the quality system and concluded with the following improvement opportunities:

- The first set of methods and objectives to achieve the required quality needs must be completed

- Continue with the implementation of the Business Plan according to the Thermiculite master plan.

- Quality Standard Sheets must be deployed on shop floor for all Thermiculite production line.

- Already achieved in the SOP of the 835 production line. Although, this good practice must be implemented in the other Thermiculite lines.

- Good practice of FMEAs in the T835 production line, but it has been seen that poor development of this risk analysis method is in the other lines.

- The Thermiculite 866 production line requires implementing a Standard Inspection Process (SIP) after start of production. The SIP is a concept to improve and control the quality built into the product. It consists of a number of SIP Stations through which the quality, fit and/or function of the previous set of processes is confirmed. In its place there should be an SIP tracking board.

- ANDON system and visual controls are well implemented in the T866 and CEV plants. Although, there is no sign of this practices in the 835 lines.

All the Thermiculite Range issues need to be recorded and followed in a regular basis. Use a Communication Board for this purpose.

5.16. Thermiculite 866 Project: Plan Against Implementation

In order to assess correctly the implementation of the Thermiculite production line, it is necessary to define two important aspects:

First, the SAQFD which is part of the development and conceptual design has been covered and fully implemented as described in Chapter 3 and Chapter 4. In other words, the production line has been fully designed according to the proposed SAQFD and supporting planning.

The detailed design and implementation are included in the Thermiculite Master Plan according to the sequence shown in Figure 4.3. The Thermiculite project detailed design and implementation have been fully recorded in the Master Plan (300 tasks). Appendix 3 includes a demonstrative small section of the Master Plan. The main sections of this plan are: organization, product trials and planning, training, product line design, plant preparation, in-plant build activities, consolidation and improvement. Considering all the tasks initially planed against to those completed, it is possible to obtain a good index of the achievements. This comparison shows that 20% of the tasks have been finished and implemented.

It is feasible to conclude that 60% of the initial plan has been implemented considering that the first four sections in the PMP are implemented, and the 20% of the tasks achieved in the Master Plan. Although, it is important to mention that this is not an indicative of the achievements in the research and this figure shows the progress in the whole project that is intended to be completed by 2016 for the start of production. The achievements regarding the research and further work can be referred to Achievement (Section 6.1) and Further Work (Section 6.2)

5.17. Chapter Summary

This chapter describes the technical development of the Thermiculite 866 from April 2010 when Flexitallic intended to adopt a batch process as result of scaling up the previous laboratory production methodology. Workload and facility analysis demonstrated that the resources needed for batch manufacturing increase linearly when demand grows. In fact by 2015, the projected utilization of the drying facilities would be 88% of its total capability. In addition, factors such as material handling and transportation promote continuous flow implementation. For this reason, it has been identified and designed a flexible manufacturing system in terms of production capacity whilst developing QA. The SAQFD for Thermiculite 866 performed a key role in the layout design and equipment selection. In fact, this chapter shows the utilization of the SAQFD proposed in Section 3.2, and the benefits of the Workforce and Strategic Alignment in the design of the Thermiculite 866 production line. The HoQ in the SAQFD produced sixteen design requirements and eight customer requirements (product technical requirements) and twenty-eight relationships. In addition, the Strategic Alignment analysis produced the Implementation Plan with four hundred specific tasks to be delivered in the next two year implementation. Finally, the brainstorming prior the formal HoQ delivered enough documentation to define technical requirements, and raised forced design requirements such as the change of product characteristics by increasing the solid contents to improve the line throughout.

The second valuable outcome of this chapter is the definition of the drying strategy or "four conveyor" strategy that intends to increase drying capacity by increasing the drying area with a 90 ^{O}C continuous drying solution supported by zoned ovens. The third major outcome from this chapter is the detailed design and the improvement of the mixing cycle using a DOE approach. The analysis of previous trials would be based on finding trends in the WPUA standard deviation. This DOE approach defined general interdependency between mixing parameters and product features. To define the new mixing cycle, a "mixing energy" analysis based on mixing parameter and Weigh per Unit Area (WPUA) checks was developed. Moreover, this chapter includes a summary of the QA system supported by a robust mixing cycle and controllable spreading using a control mass flow mechanism CFV. In addition, the QA would be supported by a laser thickness measurement, which would warranty 100% measurement after the consolidation of the Thermiculite sheets. Additionally, QA management would be supported by statistical sampling from the material packaging equipment at the end of the line. Finally, a continuous improvement cycle supported by organizational development would continuously improve quality and productivity in the production line.

6. CHAPTER 6

DISCUSSION AND CONSOLIDATION

The methodology developed in this thesis for the design of high volume manufacturing systems was successfully proposed and tested in the implementation of Thermiculite production line at Flexitallic in Cleckheaton during the period from April 2010 to August 2011. The Thermiculite 866 conceptual design has been already successfully defined and some of the manufacturing processes, such as mixing and casting, have been implemented and improved (Section 5.7 and 5.8). In addition, this Thesis has defined an innovative methodology to design high volume production lines and a SAQFD based on the Thermiculite 866 case study. The major contributions from this project are summarized in the Section 6.1 and 6.2.

6.1. Achievement of Objectives

The project planning which relies on incorporating new methodologies developed by the author demonstrated to be effective in SMEs such as Flexitallic. The proposed SAQFD and the Batch/Flow matrix simplified the decision making process to adopt and design of production systems which reduces time to market. In fact, as mentioned in the advantages of SAQFD the Houses can be reduced to 3 from 4 houses. In fact, the SAQFD and the innovative Factory Planning Methodology are the key methodologies to achieve this statement. Furthermore, all the theory methodology applicability has been demonstrated during the design and partial implementation of the Project Thermiculite 866. Finally, the key relationships between variables defined in the SAQFD were probed to be effective by the entire implementation of the mixing system and mixing cycle definition.

6.2. Implementing Change at the Thermiculite Line

The KTP aims to support SME projects by allocating The Technology Strategy Board grants and promoting change in the organization through KTP associates. For this reason, as a KTP associate, the author actively participated in the implementation of change at Flexitallic and particularly in the Thermiculite 866 project. This thesis develops several novel plant/layout design techniques and project management procedures that moved some project team members out from their comfort zone.

It has been encouraging for Flexitallic to adopt some of the proposed practices such as communication between different managerial levels and departments within the organization. For example, the Product Development team used to design and implement processes without poor or not involvement of other areas such as Operations and Quality. This 'over the wall syndrome' creates disturbances when processes are handed over to manufacturing. By using the approach suggested in this thesis, internal communication was promoted and more contractors were involved. In addition, future commissioning and equipment implementation have been highly supported by trials and continuous communication with contractors and suppliers. In fact, Flexitallic defined payment terms and internal approbation gates based on trials that were included in supplier's proposal.

In addition, this thesis proposed two innovative outcomes to promote communication and concurrent engineering in the Thermiculite 866 design:

1. Proposed Conceptual Factory Planning Methodology supported by a Flow/Batch comparative matrix.

2. The SAQFD

Finally, three major organizational and cultural changes were promoted in the implementation of the Thermiculite 866 line:

1. Concurrent Engineering as a fundamental part in project management to promote team-working practices and warranty successful equipment selection.

2. Business/Commercial Awareness as a fundamental criteria for research & development in order to warranty cost effective product and process development

3. Introduction of world class KPI in the Thermiculite 866 line to establish a solid base for production control and a sustainable business grow expected by 2016.

6.3. Product Development and Manufacturing Design

The Batch / Flow Comparative Matrix (Figure 3.4) provide the first outcome to define the impact of product features in process design. In addition, the analysis of volumes performed in Section 5.2 produced figures of manning, investment and line capacities. It was concluded that the batch process would require three times the amount of manning required by the proposed line-flow equipment-paced.

As explained in the Batch / Flow Comparative Matrix, Flexitallic needs to ‘fill a gap’ to achieve the required production control to manage with the future high volume requirements. For this reason, the Flexitallic team must design, develop and implement the Thermiculite Business Plan according to the Flexitallic vision/mission and values: quality, production, H&S and PDSA Deming’s cycle. The Batch / Flow Comparative Matrix successfully defined key parameters to analyze and define the requirement of product, process and supply to adopt flow concept under specific product and manufacturing conditions. In addition, this matrix proposes clear Lean Manufacturing requirements to reach required production control levels and obtain continuous flow rewards.

The Proposed Conceptual Factory Planning Methodology (Figure 4.3) is the simplification of three different methodologies that consider the company strategy, material flow and layout design. The aim of this methodology is to promote cooperation and communication within different departments at the company and support every stage with experimentation.

The Thermiculite 866 case study provided a view of the application of the Batch / Flow Comparative Matrix and the methodology to define the gap between Batch and Flow concepts. Finally, the Proposed Conceptual Factory Planning Methodology is the core of the Thermiculite 866 line design and the outcomes has been seen in the implementation of the project during 2010. Finally, the success of the proposed Methodology has been demonstrated with the current implementation of the Thermiculite 866 line.

6.4. SAQFD and the Research Objectives

This section aims to summarize the achievements according to the research objectives defined in Section 3.3.

Research Objective 1: Identify the limitation of classical QFD to produce a base for a QFD development.

The classical QFD methodology represents a challenge for many SMEs due to the complexity of this method that is explained in Section 2.6.2. Furthermore, the process can be demanding considering the resource available in SMEs for the probable loops required after reaching House III. On the other hand, the effectiveness of the QFD for NPD has been broadly tested around the world since it was proposed by Akao in 1978. After this date, there have been developments in TQM, Concurrent Engineering and Lean Manufacturing as mentioned in Chapter 2. For this reason, the classical QFD lacks of a method to introduce commercial awareness to avoid erroneous conclusions that are not aligned to vision and mission of any specific project or company. The classical QFD do not consider the fact that nowadays commercial requirement influence product features. For example, the automation of Thermiculite 866 packaging was forced and forced a drying process and product features. The classic QFD lacks of this upstream flow of information from House IV. To conclude, this thesis aims to improve the classical QFD to by increasing flexibility to SMEs practitioners that usually require to integrate product and process development.

Research Objective 2: Develop a methodology to produce a SAQFD and the supporting management approach to support the product and process development.

The SAQFD is an alternative approach that does not change the QFD structure, and force variables in the HoQ according to stakeholders' requirements, process planning and production planning. First, a strong and well-defined team is required for the project success. Second, the team's problem resolution techniques need to be understood in the organization to discuss, document, and share process definition before the HoQ. SAQFD simplify the QFD methodology and integrate narrowly the different requirements such as technology, reliability, and implementation cost prior to HoQ. SAQFD provides a structured and flexible approach for designing or extending a high volume production line at any stage of the product lifecycle. The method and detailed description of each step are in Section 3.5 and Section 3.6.

Research Objective 3: The benefits need to be assessed comparing the classic QFD and the SAQFD.

The proposed Novel-QFD saves time and provides a flexible approach compared to the original QFD. In addition, aligns the organization and defines major features in any stage of the product's life cycle. The SAQFD has a potential to reduce 25% the QFD practice because houses can be emerged which reduces analysis of variables. The Thermiculite 866 case study provides a good example of this in Figure 5.7. The Thermiculite 866 study case demonstrated that SAQFD supports product development from experimental processes of laboratory scale products. In fact, the case study demonstrates the application of the SAQFD theory by considering the current process limitations in the laboratory scale production line and stakeholders' needs.

6.5. Further Work and Dissemination

This section includes next challenges for further case studies to proof the SAQFD theory. In addition, requirements to complete the implementation of the Thermiculite 866 line in the following two or three years. Flexitallic will continue in the implementation of structured management of product development and continuous improvement. Following sections describe three fronts of further work.

6.6. Line Production Design and SAQFD Further Cases

The methodology to design and implement the Thermiculite 866 line proposed in this research has been tested partially with the implementation of one half of the production line. Although, the proposed flow/batch comparative matrix and SAQFD should be run in other projects at Flexitallic to improve their approach and test its effectiveness. This requires further engagement from the company to introduce structured product development and controlled launches. For this purpose new and current staff in product development and operations should be trained and encouraged to follow a structured and analytical procedures to make decisions in launch projects. In fact, Directors and Managers should base their decisions on forecasted demand and production scenarios as suggested in the "strategic alignment" of the SAQFD. This is possible only in a structured and linked organization with clear roles and KPIs in place. There is a good opportunity to utilize a SAQFD approach in the redesign of the "forming head" of the Thermiculite 835 which is a polymer based version of the Thermiculite 866. In conclusion, SAQFD requires further case studies to reinforce its effectiveness and provide further proof the assumptions stated in this thesis. In fact, SAQFD should be run in a company where classic QFD has been successful. Even though, it is important to mention that this would not question the advantages of integration in the organisation proposed by the SAQFD.

6.7. Communication and KPIs

Continuous improvement must be implemented in Flexitallic as part of the day-to-day management activities. This would be possible by implementing a wider HR program to motivate people on the shop floor and middle managers. One of the key factors for leading an organization to continuous improvement is maintaining clear and direct communication between the shop floor and white-collar workers. The structured project management approach proposed in this study needs to be supported by training and communication strategies within the organization. The development of the Thermiculite 866 project required continuous communication and training of people on the shop floor. In addition, it is important to mention that a robust organizational structure in Operations is fundamental to tackle challenges of change and maintain team synergy whilst promoting open communication. This would be part of further development of a Departmental Business Plans and Production Planning Control.

Manufacturing system KPIs provide opportunities for standardisation, communication and tracking continuous improvement. The Thermiculite 866 plant is required to use these KPIs to communicate key manufacturing strategic objectives to all employees and accelerate continuous improvement in their working area. KPIs would be displayed throughout Flexitallic to enhance communication. For optimisation of the plant manufacturing system, these KPIs will be analysed as a group. Since optimisation of any one indicator can be detrimental to another, for this reason, the indicators will be analysed as a set in order to manage improvement strategies and resources. As it has been stated in previous chapters, KPIs need to be controlled to support QA in the supply chain. In fact, one of the major customers requires Vendor Quality Assurance system (VQA) to ensure that unqualified product, in terms of feasibility and materials are not chosen or approved at Flexitallic.

6.8. Process Development and Experimentation

There are specific processes which need further development. For example, drying needs to be fully understood and implemented to support the 2020 demand. All efforts to reduce drying time are by increasing moisture extraction capacity although there is still the option to increase solids in the TH 866 mix. This approach would change some of the parameters during casting although those changes would be justified in order to increase manufacturing capacity. Finally, it is important to see if there is any implication in the Thermiculite 866 sealing properties by introducing drying cycles in drying process.

Most of the trials are based on testing one variable at a time, although, other multiple variation Taguchi methods should be explored in the future. There were a number of trials that supported the detailed design and experimentation in 2010. For example, different concepts were tested, such as the vacuum oven, zoned and continuous oven concept, and different types of mixers. In addition, there is a great opportunity to analyse the 866 nanocomposite structure to understand the disassembly of the vermiculite stacking and/or reduction of the links in the structure during mixing.

Finally, there are good Lean Manufacturing practices to be implemented such as FMEAs, quality control operation system, detailed SOP, ANDON implementation and Standardised SIP which is a concept to improve and control the quality built into the product. It consists of a number of SIP Stations through which the quality, fit and/or function of the previous set of processes is confirmed.

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APPENDIX 1

THE STRATEGIC ALIGNMENT OF QUALITY FUNCTION DEPLOYMENT (SAQFD) AS A KEY DRIVER FOR THE DESIGN OF A HIGH VOLUME PRODUCTION LINE

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ABSTRACT

This paper covers the introduction of a novel Quality Function Deployment (QFD) to support the manufacturing line design using a mechanism of incorporation commercial awareness in any stage of the product deployment. The original QFD ensures process planning by bringing parts deployment into parts characteristics through the House of Quality. This study renews the original QFD by developing the Strategic Alignment of Quality Function Deployment (SAQFD) to achieve proactive management of Houses III and House IV. The design of SAQFD is based on Neo-QFD that has been proposed during the last ten years by different authors. Finally, the SAQFD applicability is demonstrated during the implementation of the Thermiculite 866 high volume production line.

Keywords: Quality Function Deployment, Quality Assurance System, Quality Management.

1 INTRODUCTION

Quality Function Deployment (QFD) has continued to spread since Mizuno and Akao published their first book on the topic in 1978. This paper intends to identify the best utilization of the QFD as an important section of Total Quality Management (TQM). The modified QFD approach integrates product and process development (IPPD) as an extension of concurrent engineering in the design of a high volume production lines. The main QFD method was not modified, and it has been proposed the use of a systematic way to conduct integrated product and process development. The proposed QFD approach is driven by business priorities and adapts the differences in applications resulted from changes in product development. This approach is presented in the Thermiculite 866 case study, although, this paper does not include any technical specification that would compromise any intellectual properties of the Thermiculite 866 or manufacturing process at Flexitallic Ltd.

The term "Quality Function Deployment" (QFD) refers to the concept and methodology of New Product Development (NPD) under the umbrella of TQM. The QFD is a methodology for transforming the customer's requirements into product characteristics and further more into process and production characteristics. QFD uses four "houses" to integrate the information and requirements of marketing, engineering, R&D and manufacturing. According to the first traditional scheme published by Mizuno and Akao in their first book in 1978; there are four houses: House of Quality, Parts Deployment,

Process Planning and Process and Quality Control (1). Despite the popularity of this concept, Shiu (2)claims that there have been several misperceptions about the "QFD essence". The common misunderstandings include the utilization of the Quality Deployment equivalent to "quality chart;" and QFD being equivalent to quality deployment (2).
Pinto and Kharbanda (3) identified other major causes of NPD failures such as ignoring the project environment, stakeholders' requirements and project objectives.
The broad concept of quality and its philosophy provides different possibilities to alter the basic QFD concept and redefine a Neo-QFD to achieve an optimal product development. The structural change of the "four houses" has produced different approaches and new variables into the practice of QFD for product development. For example, the Matrix of Matrices Model deals with quality, technology, reliability and cost considerations in addition to the popular QFD Four Matrices. This modified QFD approach aims to extract any bottleneck-technology, to prevent potential failures and to achieve target cost. The development of QFD has demonstrated that modern product development requires more accurate market analysis and business integration, although, this continuous sophistication of the QFD has brought other issues in the information management.

2 FURTHER DEVELOPMENT IN QUALITY FUNCTION DEPLOYMENT

Several problems can be encountered during the implementation of sophisticated QFD. For example, erroneous conclusions can be magnified by serial processing. Therefore errors introduced at one stage will propagate to the entire analysis. In addition, Han (4) argues that the QFD complexity may be a time-consuming process requiring a lot of detail. In fact, 30 customer requirements and 50 design requirements lead to 1,500 different links to be discussed. This is a real issue for QFD practitioners considering that a typical application can have 30 to 200 requirements (5).
The QFD literature has demonstrated that there is significant complexity in the use of rating scales to prioritize the QFD final outcome (6). Furthermore most QFD researches have focused on the scoring mechanics (2).
Ten percent of the QFD practitioners use the four-matrix model; another 10% use the Matrix of Matrices approach exclusively. Finally, the remaining 80% use an integrated approach combining the best features of both models. This clear message defines the importance of "customized" QFD in order to achieve practicality in the industry. For example, Marsh (7) integrated a model based on Deming's Plan, Do, Check and Act (PDCA) cycle in order to link QFD with Lean Manufacturing philosophy. In fact, this seems to be the start of more customized approaches. For example, ten years after the first QFD publication, some practitioners intended to link QFD to technology, cost and reliability in NPD cycle (2). Furthermore, Zultner, a student of Akao, designed a streamlined approach called "Blitz QFD" that intended to select and deploy only the top most influential customer needs (8).

3 ALTERNATIVE QUALITY FUNCTION DEPLOYMENT

Sullivan (9), and Clausing (10) were important figures in the initial development of QFD in the industrialized Western countries. Afterwards, QFD was gradually introduced to researchers and practitioners in different of manufacturing fields. Then, QFD was combined with various design methodologies and numerical analysis methods that promoted more research afterward. Jiang (11) defined three main aspects that have been explored:

a. QFD combined with TRIZ, Taguchi methods in order to improve its effectiveness
b. QFD as part of product design and process design
c. QFD combined with numerical methods in order to strength the analysis accuracy

3.1 Commercial awareness as a mechanism of knowledge incorporation in QFD

The level of TQM and ISO9000 development defines the major quality methodologies in organizations. Historically most of the organizations in Europe were more exposed to ISO9000. Although, there are several important reasons to promote TQM in this companies. Planning and QFD intends to improve new product development and reduce delays in projects. This paper proposes a renewed approach to use the original QFD and integrated organization objectives during product development. The Flexitallic Thermiculite 866 project is an illustrative example of the methodology proposed to deploy the quality system using a "forced QFD".

As mentioned in the introduction of this study, "Neo-QFD" provides several reasons to promote flexibility and customization to the original QFD. In fact, there are several aspects to be covered in QFD. For example, cost and product life cycle are important inputs to be incorporated in the analysis. Several authors have assertively implemented more sophisticated QFD scoring mechanisms. Although, these approaches constrain the QFD due to the excessive time required for its implementation. On the other hand, the proposed QFD must promote communication to improve product development. Successful companies optimize product life-cycle designs by employing well organized design reviews and utilizing the culturally inherent communication between designers and engineers responsible for production and maintenance.

The aim to envisages the process prior QFD has been a common point of view among QFD practitioners. Han (4) proposes a hierarchical framework to improve the effectiveness of decision making. This Hierarchical framework suggest six stages before starting the house of quality: voice of the customer, competitive analysis, and voice of the organization, design targets, relationship matrix and correlation matrix. In fact, the initial forced priorities often depend on product positioning in the market and life-cycle. For example, QFD initial priorities should be affected by the role of product features, cost, and time to market. Chao (12) proposes a matrix that begins by identifying constrained factor (e.g. hard limit on time-to-market, hard budget/cost target, a new level of features/functions). Second, the priority to be optimized needs to be defined (e.g. quicker time-to-market, minimize cost, maximize features). Furthermore, Sarbacker (13) identified the importance of risk assessment in three main aspects: Envisioning risk, Design risk. And Execution risk (12).

The quality function deployment (QFD) is one of the most important part of the total quality control concept. It focuses on customer needs determination and on organization-wide commitment to satisfy these needs in the long term. Lu (14) suggests that the application of QFD in the strategic planning process could be applied for corporate departments such as marketing, finance, accounting, research and development, etc. (14).This view incorporates corporate strategy into the process to decide about products, processes and operations, and suggest continuous reviews of customer strategy. In addition, Killen (15) suggest that QFD-based methods should start with customer and stakeholder outcomes. Finally, the inherent culture of the company is an important driver for the application of QFD. For example, in companies that emphasize new product development, the "forced product features" involve the setting of product specifications. Early stages of the QFD begin with demanded-quality deployment, and determine critical quality characteristics and design quality. On the other hand, in companies that emphasize manufacturing, the QFD activities begin with acceptance of product specifications. Demanded-quality deployment and quality planning before the setting of product specifications.

4 THE STRATEGIC ALIGNMENT OF QUALITY FUNCTION DEPLOYMENT (SAQFD)

As explained in the previous sections the original QFD supports modification. This study proposes a Neo-QFD defined by forcing some of the product features and process requirements prior to starting the first House of Quality. The application of "inherent" commercial strategies leads to define the optimal process specifications for specific components. This paper intends to prioritize stakeholders' requirements and commercial awareness as a key factor to define QFD requirements. Company situation defines restrictions in the development of NPD. For example, economic stability, investment in the NPD project, staff skills and education are key factors to define the scope of the level Quality Assurance (QA) implementation. In addition, infrastructure and inherent policies have an important impact significally in the approach to the NPD. The SAQFD propose two fundamental conjunctions to link marketing plan and corporate strategy to QFD. This key grouping are Workforce and Strategic Alignment displayed in Figure 1.

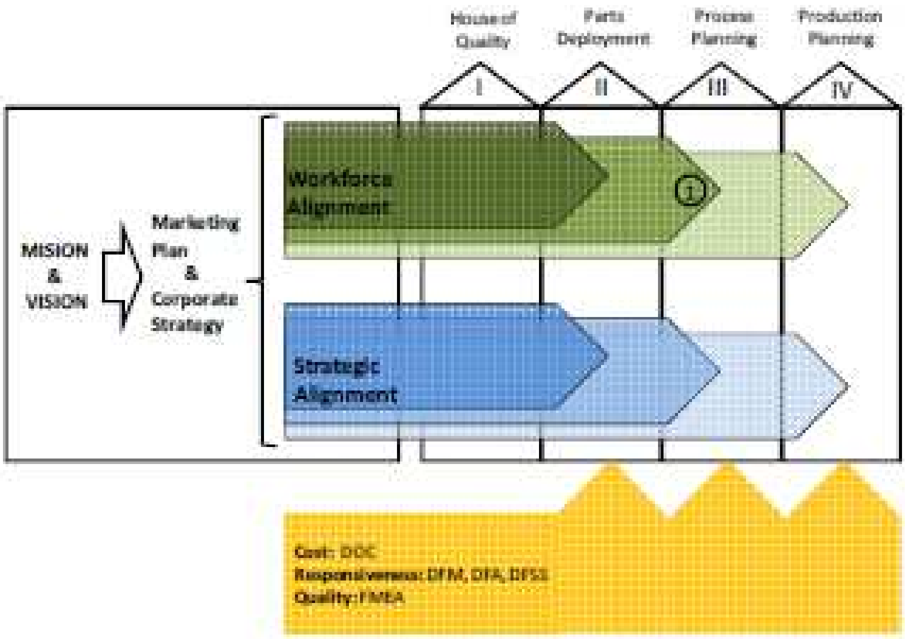

Figure 1: The Strategic Alignment of Quality Function Deployment (SAQFD)

SAQFD can be represented by two main streams of influence and information: Workforce Alignment and Strategic Alignment. Both of these sources of forced requirements will define a Neo-QFD shaped by organizational mission & vision through corporate strategies. In Figure 1, the QFD structure is represented by the four Houses of Quality, and the introduction of specific requirement is represented by green and blue arrows. For example, the number one in the circumference represents an early forced requirement in the process for one specific teams involved in the QFD. The specific requirement may be the use of Design for Manufacturing (DFM) to modify product features instead of filling the gap, for example, of poor skilled manpower or technological restrictions. This demonstrates how a specific solution is forced to product redesign instead of influencing the process redefinition to accomplish customer requirements. This downstream feedback might be considered an atypical modification of the QFD, although this is fully compatible with new Concurrent Engineering practices in product development. In fact, SAQFD provides a structured development process for companies that need to include their limitations during NPD. The major difference with the original QFD developed by Akao is the importance that SAQFD gives to business awareness and the relative flexibility required during the HoQ. This means that Operations needs to interact closely with Designers to define some parameters that would be reflected in the product. SAQFD requires specialized support analysis in three major fields: cost, responsiveness and quality to support any forced requirement in house I, II, III or IV. The brownish base in the bottom of the graph represents the set of product development techniques to facilitate the introduction of any feedback or loop to HoQ.

The Workforce Alignment or Organizational Alignment, which is part of a greater Human Resources study, is partially covered in this paper. Each department in the organization need to understand their specific role and responsibility in each specific stages of the project. The communication between department and the ability to identify some of the requirement in the different Houses will define the success of the NPD. Ideally, the SAQFD should start by involving people from different levels in implementing and thinking about company practices. Provide feedback to management and engineers on cost-effectiveness and project specific aims. It is important to use factual information about what is happening based on an unbiased objectives with informed staff. After defining teams and their roles, try to answer what they are trying to accomplish and define some specific roles. Are the company vision and mission aligned? Major requirements should sound like solutions but avoiding the high-level project goals and challenges, like "make cheaply", "produce better quality", and "meet new demand". The flow of information and involvement of the team is a key factor for defining successfully the Strategic Alignment.

The Strategic Alignment adapts the original QFD to the business perspective requirements in order to effectively implement process planning and production planning. A well informed team promotes ideas from different hierarchical levels which produces valid forced relationships. The business and company philosophy defines the major project drivers. For example, a company that prioritize manufacturing upon other departments might promote production capacity and capability as part of the Strategic Alignment. The Workforce would be aligned under a Manufacturing leader that would manage the project to fulfill operations requirements. A successful Strategic Alignment produces a detailed project plan with tasks within an specific timescale. The SAQFD will define the structure of this plan based on the four QFD Houses: Engineering Characteristics (House of Quality), Parts Characteristics, Key Operations Process and Production Requirements. This plan structure is based on Fundamental Principle of System Engineering which suggests to start with a conceptual design and continue with detailed design. The mechanism to define each section will be based on the Plan, Do, Check, Act Deming Cycle, and supported by Facility Planning Project and Design. In this stage, the SAQFD would produce a detailed project plan and all of its advantages. For example, it would be possible to identifying a "critical path" and the necessary backup plans can be addressed to accomplish a success NPD. To conclude, the SAQFD provide an improved utilization of the original QFD approach by developing a strategic plan that consider the project environment such as company vision.

4.1 Introduction to the Solid Oxide Fuel Cells and Definition of Basic Customer Needs

Solid Oxide Fuel Cells (SOFCs) are highly efficient energy conversion devices that produce electricity by the electrochemical reaction between fuel and an oxidant. Fuel-cell devices are composed of an anode electrode (exposed to the fuel), an electrolyte and a cathode electrode (exposed to the oxidant). These components are stacked to produce enough electricity and heat to be recovered. This sealing solution for this technology has several key factors that need to be accomplished: The materials selected as sealants must be thermo-mechanically and thermo-chemically stable in both oxidizing and wet-reducing environments at 800 ·C for long-term exposures (500–1000 h) (16).
Smeacetto claims that five main approaches are being studied for sealing SOFCs (17) & (18) : brazing, compressive seals, glass, glass–ceramic and glass-composite seals. Flexitallic designed Thermiculite 866 as a compression seal for Solid Oxide Fuel Cells (SOFC), and other range of applications. Furthermore, the SOFC market needs an effective solution with reduced prices considering that other technologies, such as gas boilers, have defined a low reference price.

5 SAQFD CASE STUDY – THE THERMICULITE 866 PROJECT

Thermiculite 866 is based upon the use of extremely thin, flexible plates of the natural mineral vermiculite. Vermiculite is the short mineroligical name for hydrated laminar magnesium-aluminum-ironsilicate which is similar to mica in appearance. This material is known for high temperature capability, high chemical resistance and as an electrical insulator. In addition, Thermiculite 866 has a second material which is steatite, another silicate with a plate-like crystal structure, which is perhaps better known as talc or soapstone. The combination of steatite, a very soft mineral, with the Chemically Exfoliated Vermiculite (CEV) results in a soft sheet material that compresses under modest loads and this means that on assembly of a connection it conforms easily to the surfaces thus forming a seal (19) Thermiculite Critical Service materials are rated for temperatures up to 1000°C and have passed the API 607 fire test. (20)
SAQFD for Thermiculite 866 starts with the Organizational Alignment or Workforce Alignment as mentioned in the previous section four. In order to understand their impact and involvement in the project, the stakeholders and team project members were grouped into three different hierarchical groups according to the power to force a variable or ownership of the project:
Priority 1 - Project Owners - They have high interest in the commercial and economical success of the project. Their main goal is to accomplish the levels of production, quality and flexibility required for the future Thermiculite 866 demand. In addition, they are looking for revenue and investment return periods.
Priority 2 - Project Developers - They are the experts in the product, materials and manufacturing process. In addition, in this group, I included the academic supervisors who transfer knowledge from the University of Bradford.
Priority 3 - Project Coordinators and Executors - They are the people that perform the required tasks to support the design, commissioning and implementation of the

Thermiculite 866 production line. They are considered "partial-stakeholders" because their role change from internal customers to providers along the project.
The first outcome from the project owner was a general Marketing Plan & Corporate Strategy for the Thermiculite 866. The plan for the Thermiculite 866 production line implementation is defined by the SOFC technology development during following years. It has been predicted that the Thermiculite 866 demand would increase 300 times for one of the SOFC major customers during the next four years. This is a major concern that defined two forced inputs for the process and production requirements in the SAQFD:

a. Expected high volume production line needs to be considered in the QFD Process Planning
b. Production volume ramp-up in 2015 year must be considered in the QFD Process Planning & Production Planning

Due to the novel nature of the SOFC market, it is important to get to the market and support customers with their technical challenges by aligning strategies according to their demand requirements. The original target was to design and to implement a high volume production line to introduce the Thermiculite 866 range by 2015, but the SOFC development and experimental phases were delayed ten months. For this reason, the Production Line implementation would be accomplished by implementing modular equipments concept during the following years. This is and example of Workforce and Strategic Alignment, and first important milestone of the SAQFD, in the design of the Thermiculite 866 production line.
Figure 2 displays in a green arrow the organizational prioritization of R&D and their definition of the process as a key driver to develop the product. On the other hand, Manufacturing and Engineering act as project developers and support R&D objectives. In addition, the impact of the expected sudden demand ramp up is represented by the forced requirement of modular high volume capacity line.
The SAQFD suggest to force those requirements during the first House of Quality (HoQ) and identify them through the entire QFD. The mechanism to introduce these requirements is by using a team solution technique to tackle the proposed forced variables. For example, workshops and brainstorming sessions, before the HoQ session, would communicate and fix the strategies in the team's perception. After that, the HoQ can be deployed with the team and some of the previous conclusions can be included in the Design Requirements row. The HoQ for Thermiculite 866 defined, after brainstorming with the Technical Team, the following main conclusions:

a. Operations mechanisms and technology requirements to reach high volume production of the Thermiculite 866 by 2015
b. Quality Assurance needs to be linked to the Manufacturing Process

The major outcomes from the brainstorming were used as forced design and customer requirements. For example, the drying time was defined as process bottle neck and its forced design requirement to maximize throughput by probable increase of the Thermiculite 866 solid contents in the wet material. This is a good example of how SAQFD promotes loops from the House III to HoQ to change product specifications when required. This early feedback is valuable to gain time and other resources during novel products development.
On the other hand, the reader must understand that the Thermiculite 866 project intends to use some of the experimental equipment to construct the future high volume production

line. For this reason, most of the Engineering Characteristics were defined from the third house (Process Planning), and the proposed Strategic Alignment is applicable to the Thermiculite 866 project. The manufacturing of the Thermiculite 866 has four main processes: mix, spread, dry and rolling. As stated in the introduction of this paper, no technical data will be presented, and the main relationships that where defined in the HoQ are:

a. Density of the Thermiculite 866 dough as a key driver of other product features such as Weight per Unit Area (WPUA) and settings of the spreading head settings
b. The mixing settings would have a moderate impact on the WPUA and probably a weak relationship with the specks presence
c. The cost of the product and production capacity may be strongly affected by Drying capacity and it has a close relationship with the supply of raw material from alternative resources
d. The importance of the material formulation was defined as priority 5 above WPUA and thickness

The HoQ produced sixteen design requirements and eight customer requirements (product technical requirements) and twenty eight relationships. Considering the outcomes of the House of Quality (HoQ) and Strategic Alignment, the diagram of the Strategic Alignment of Quality Function Deployment (SAQFD):

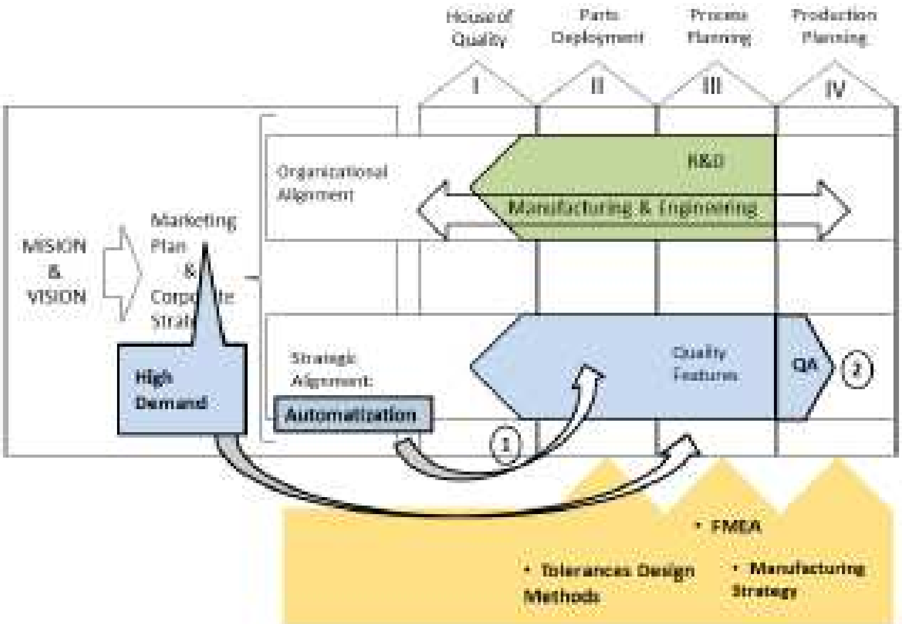

Figure 2: The Strategic Alignment of Quality Function Deployment for the Thermiculite 866

The SAQFD is especially useful for new product development, as the Thermiculite 866 project, that was not originally conceived from the HoQ. As explained in the introduction of this paper different authors designed more specialized approaches to support the first

HoQ. Four methodologies to improve the Thermiculite 866 quality, cost and responsiveness are explained bellow.

FMEA: However, the original QFD did not emphasize the implementation of the process design FMEA, it is necessary to add this analytic mechanism to the proposed SAQFD. The Flexitallic team developed a FMEA to envisage any problem in the Thermiculite 866 manufacturing process. The team envisaged potential minor variable during spreading and potential significant variation during ingredients weighing.

Tolerances Design Methods: Weight Per Unit Area (WPUA) is a key parameter that need to be monitored and analyzed with statistical methodologies. The analysis of standard deviations would envisage important variables relationships in the processes and provide valuable information for Quality Assurance (QA) and automatization.

5.1 Case Study Analysis and Outcomes

Automatization implemented at any cost: Considering the circled number one in Figure 2, which is a forced requirement of automatization. It has been defined that automation need to be considered for production capacity improvement and QA. The automatization of the cutting and packaging system increases the capacity of the line. In addition, the control of critical parameters such as raw material weighing, mixing cycle parameters, spreading head settings, WPUA and thickness checks are important for QA. The automated system requires a centralized information system to control QA in the line.

Quality Assurance defined from Process Planning: This forced requirement is represented by the circled number two in Figure 2. The impact of this requirement on the Thermiculite 866 high volume production line is that the QA is defined according to the process limitations rather that the product features. For this reason, the Thermiculite 866 QA is based on process control rather than product checks. In fact, the process control affects the product specifications through a simple lineal relationship. The density/mass/volume equation defines the required control system loop for controlling the dough spreading process according to QA requirements.

The Themiculite 866 SAQFD in detail: The SAQFD process required about four months from the team definition to define most of the process planning (House III). The Thermiculite 866 project team provided the expected organizational alignment and engagement with the project. Although, its definition and official presentation was delayed because it was the first time the QFD methodology was performed at Flexitallic. Regular meeting reviews permitted to define major requirements for the project and requirements for the SAQFD.
The Strategic Alignment analysis provide a better understand of the project requirements with stakeholders and it produces the Thermiculite 866 Implementation Plan with four hundred specific task to be delivered in the next two year period. In addition, the brainstorming prior the formal HoQ delivered enough documentation to define technical requirements, and raised forced design requirements such as the change of product characteristics by increasing the solid contents to improve the line throughput. Finally, it was difficult to fully perform the Process Planning (House II) due to the unexpected outcomes from the mixing process after installing a new mixer. In fact, this issue conducted our effort to performing statistical analysis and apply tolerance design methods.

In conclusion, the SAQFD reduced time in process analysis and provided the flexibility required to design the future Thermiculite 866 high volume production line.

6 CONCLUSION AND RECOMENDATIONS

Strategic Alignment of Quality Function Deployment (SAQFD) is an alternative approach that does not change the QFD structure, and force variables in the HoQ according to stakeholders requirements, Process Planning and Production Planning. First, a strong and well defined team is required for the project success. Second, the team problem resolution techniques provide a good forum to discuss, document, and share process definition before the HoQ. SAQFD simplify the QFD methodology and integrate narrowly the different requirements such as technology, reliability, and implementation cost prior HoQ. The proposed Neo-QFD saves time and provides a flexible approach, compared to the original QFD, that aligns the organization and define major features in any stage of the product life cycle and utilize resources currently engaged in the process. For example, the Thermiculite 866 is already introduced in the market and it has been produced in a laboratory scale, so SAQFD provides the best approach to scale up the process and design the future high volume production line.

The Thermiculite 866 study case demonstrated that SAQFD supports product development from experimental processes of laboratory scale products. In fact, the case study demonstrates the application of the SAQFD concept by considering the current process limitations in the laboratory scale production line and stakeholders' needs.

The future development of the Thermiculite 866 production line will require implementing QA in the supply chain. In fact, one of the major customers requires vendor quality assurance system (VQA) to ensure that unqualified product, in terms of feasibility and materials are not chosen or approved at Flexitallic.

In conclusion, SAQFD provides a structured and flexible approach to design or extend a high volume production line to introduce new product in any stage of its product life cycle.

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APPENDIX 2

INNOVATIVE METHODOLOGY FOR DESIGNING A MODULAR HIGH VOLUME FLOW LINE

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ABSTRACT

This paper proposes an innovative factory planning methodology to achieve the objectives defined by Flexitallic for the future expansion of the Thermiculite 866 production line. The concepts under investigation extend to the analysis of flow benefits and restrictions considering product features and demand addressed in a proposed Batch / Flow Comparative Matrix. Furthermore, this study describes a Conceptual Factory Planning Methodology to incorporate new tendencies for project planning, process manufacturing design and layout design. The definition of the future value stream is based on the analysis of the process, the definition of the manufacturing capacity and future line expansion strategy. The Thermiculite 866 case study exemplified the utilization of the proposed methodologies and demonstrates its importance during the design of a high volume production line. The paper concludes that the implementation of a line-flow equipment-paced will support the future production and quality requirements for Thermiculite 866.

Keywords: Plant Design, Lean Philosophy, Flow Production Line, Value Stream Mapping.

1 MARKET AND PROCESS DEFINITION

Manufacturing has been radically changed over the past decade because the relatively 'static' nature of market now has been replaced by high changeable market requirements. The new demand is hardly satisfied by the mass production, so new terms and requirements to manufacturing are fundamental. In fact, Kidd emphasizes in Chute (1) that the need for every organization is to be able to switch frequently from one market-driven objective to another. Crowson (2) argues that most businesses get flexible primarily to reduce costs and thereby improve their competitive position in the market. However, the real objective of this investment is to make money by high volumes with reduced unit costs. The SOFC industry, because of its current low production quantities and low-rate production, has not been strongly influenced by high volume production concepts and automation requirements. Although, automation can be justified for this industry due to precision and accuracy are required.

1.1 Business and Productivity Strategy Considerations

The productivity on shop floor can be identified by six interrelated factors: Planned Production Times, Physical Working Conditions, Economic Working Conditions, Degree of Centralization for Decisions, Acceptance of responsibility, Attitude Towards Time (3).

In fact, all these condition are key drivers to warranty a production line linked to organizational priorities that according to The Department for Business Innovation depends on seven pillars of activities for success. These are: Macroeconomic Stability, Investment, Science and Innovation, Best Practice, Skills and Education, Infrastructure and Policies to ensure the right market framework. In addition, it has been stressed that infrastructure and policies should ensure the right market framework (4). In other words, every intention to implement new technology in any manufacturing process must fit the real market requirement. This concept can be extended to other manufacturing strategies such as flexibility, reliability and capacity.

Flexibility, reliability and capacity are the most sought-after properties in modern manufacturing systems, but they are poorly understood in theory and poorly utilized in practice. One reason for this is the lack of general agreement on how those terms should be applied to Manufacturing. Even though, Boyle (5) argues they are not only an operational aspect but also an attribute of decision making, an economic indicator, and a strategic tool. It must be considered that increasing the potential flexibility to a point much greater than the required flexibility may result in an over-investment in manufacturing equipment (5). For this reason, the proposed factory planning methodology define the level of flexibility, reliability and capacity during the Conceptual Design and Detailed Design stages described in the Proposed Conceptual Factory Planning Methodology.

2 FLOW PRODUCTION AND LEAN MANUFACTURING SOLUTIONS

After the World War I, Henry Ford and General Motors moved the world into mass production and flow process. The next Manufacturing milestone was after World War II when Toyota pioneered the concept of Lean production (6). Today, lots of companies have implemented their own "Lean System" and flow concepts that are based on the first Toyota Production System (TPS). Womack (6) mentioned that the success of Lean philosophy is based in the process stability which permits to combine to produce 100% quality products when they are needed to satisfy customer demand. Standardized and leveled production work which helps to stabilize the process, and Just in Time (JIT) managed by a pull system will reduce the inventory. In addition, one of the most aggressive mechanisms to implement continuous improvement is through production stop policy implementation to visualize the location of the problem.

2.1 Continuous Flow: the solution for high production volumes

In 1913, Ford implemented the mass production concept to assembly a vehicle that minimized the time that elapsed between beginning and completing production. The solution for Ford was to standardize huge volumes of products in a continuous flow and low in house inventory facility.

The second important development in the manufacturing field was the link of this concept to Lean philosophy. Minoru M. president of Toyota Motor Manufacturing implies it when he mentioned: "If some problem occurs in one-piece flow manufacturing then the whole production line stops. In this sense it is a very bad system of manufacturing. But when production stops everyone is forced to solve the problem immediately. So team members have to think, and though thinking, team members grow and become better team members and people". In addition, not only all people will be involved in the problem solution but the continuous process flow brings problems to the surface (7).

In addition, Stewart (8) claims that companies generally try to settle into more stable ways of working such as more fixed working patterns. For example, static product lines like the current Thermiculite 835 line has been a reference for product development at Flexitallic. Stewart (8) suggests that the best companies make easy to figure out the organization's structure as well as its process/flow of work through the production systems which gives inertia to the operation. This argument suggests that these organizations are always clear, visible to employees for quicker track of difficulties. Finally, visual business processes allow everyone in the organization at all levels to understand specific roles in the company and in what form their contribution has helped to the company's revenue.
Miltenburg (9), claims that "a line flow system is appropriate when the product design is stable and the volume is high enough to make efficient use of a dedicated line."
To conclude, flow is a concept developed along to the process standardization in order to reduce total lead time and promote mass production success. After flow concepts were implemented in most of the industries, the system needed to gain competitiveness through Lean practices. The Lean philosophy and TQM provides waste elimination methods and continuous improvement techniques to the system. For this reason, Lean flow system provides total customer satisfaction and employee engagement.

2.2 Lean Manufacturing and Production Lines

The intention of change in an organization is the most motivating challenge and also a scaring issue for most of the people. Change disrupts organizations and it is not an overnight process. The first step to change in a company should be promoted from top executives and transmitted to shop floor through approaches designed by Human Resources. Change cause non-conformance in the first phase which is the least comfortable for the people and a lack of stability for the operation (8).
Today, a number of companies have implemented their own "Lean System" and flow concepts that are based on the first Toyota Production System. Although, many of these companies has not been able to demonstrate the financial benefits at the overall enterprise level (10). Probably one of the reasons is that Lean has been considered as a process whereas as a philosophy Baker (11) and O'Corrbui and Corboy (12).
Unfortunately, Lean interpretation usually becomes so misapplied and the popular mentality is to do everything with less: half of the factory space, half of human effort, half of investment. Actually, most of the activities were applied in discrete activities that transformed the industry "one step away from anorexic" making them "fragile" and inflexible instead of Lean (13). On the other hand, Alavi (14) argues that there is no roadmap for achieving a kaizen or Lean culture, and suggest to left each organization to their own devices and methods.

3 INTRODUCTION TO THE THERMICULITE 866 PROJECT

Flexitallic Ltd designed Thermiculite 866 as a compression seal for Solid Oxide Fuel Cells (SOFC), and other range of applications. Thermiculite 866 is based upon the use of extremely thin, flexible plates of the natural mineral vermiculite. Vermiculite is the short mineroligical name for hydrated laminar magnesium-aluminum-ironsilicate which is similar to mica in appearance. This material is known for high temperature capability, high chemical resistance and as an electrical insulator. In addition, Thermiculite 866 has a second material which is steatite, another silicate with a plate-like crystal structure, which is perhaps better known as talc or soapstone. The combination of steatite, a very soft mineral, with the Chemically Exfoliated Vermiculite (CEV) results in a soft sheet material that compresses under modest loads and this means that on assembly it conforms easily to the surfaces thus forming a seal (15).

The aim of the Thermiculite 866 project is to design and commission the implementation of a high volume production line or batch process to provide gaskets for the SOFC industry that may generate £7m per annum income to produce a good financial return. The Thermiculite 866 production process requires accurate controls to warranty the product's quality. For this reason, a Strategic Alignment of Quality Function Deployment (SAQFD) was developed to define the major requirements in the future production line (16). This Neo-QFD approach delivered strategic alignment in addition to engineering and customer requirements. The required high volume production line must support a production quick increase for 2015, and warranty supply of Thermiculite 866 sheets for probable UK SOFCs market that is projected to be 1,600,000 per year (17) .

This study proposes a methodology for designing a modular high volume line supported by the strategic alignment defined during the Thermiculite 866 SAQFD.

4 BATCH / FLOW COMPARATIVE MATRIX

In section 2.1, several strong reasons were exposed to promote implementation of flow line, although, further analysis needs to be conducted to design a suitable production solution for Thermiculite 866. SOFC technology has been developing for the last eighty years and its high technical requirement and expensive materials have not permitted to start high volume production regimens. For this reason, the SOFC industry has had reduce contact with high volume production line challenges. Flexitallic will face several challenges such as required operators' skills and high level of operations management, etc.

At Flexitallic, the Thermiculite 866 demand has been forecasted to increase three hundred times compared to the current demand during the next three years. Although, the next couple of years the demand is expected to slightly increase. This means that the Thermiculite 866 implementation needs to be highly reactive to considerable demand acceleration by 2015 to 2020. For this reason, the new Thermiculite 866 production line requires a flexible concept to justify budget expenditure according the forecasted demand. The definition of a particular production line can be based on the evaluation of product/volume – layout/flow matrix proposed by Miltenburg (9) that provides a general description of different layouts and types of operations. This paper suggests a novel comparative approach between batch and flow to justify a strategy and future expenditure in the implementation of any high volume production line. The layout can be easily defined by using the link to the material flow and process flow. In fact, the material flow depends on the layout, but a particular layout can vary according to the operation. Consequently, this study proposes a structured evaluation matrix to define the product and operation according to different production parameters such as product, process and material supply.

In Figure 1, the first column displays three concepts required to achieve Flow, and the difference with Job Shop and Batch operations. On the top of the matrix are displayed different levels regarding Lean Manufacturing Controls that promote reduction of variation in the process. The sloped arrow represents the additional controls required to achieve higher Lean Manufacturing levels to support Flow process. Finally, the Thermiculite 866 project is represented by the orange box and some specific improvements of the current experimental production line such as layout redesign and

Strategic Aligned Quality Function Deployment (SAQFD). The matrix proposed to evaluate three production features: product, process and production control in order to define the required action to pass the barrier between batch and flow.

The Batch/Flow Comparative Matrix (Figure 1) displays an analysis of the current Thermiculite 866 process based on process, product and layout concepts previously explained. This analysis intends to summarize the product characteristics and required operational improvements to implement and achieve the reliability of a high volume manufacturing production line. The red dots represent the current possible limitation for the flow implementation at the Thermiculite 866 production line. Two of those requirements: pull control and control boards will be achieved with the implementation of the Thermiculite 866 project. Although, there is a product volume demand that is a fundamental requirement to get the advantages of the flow concept.

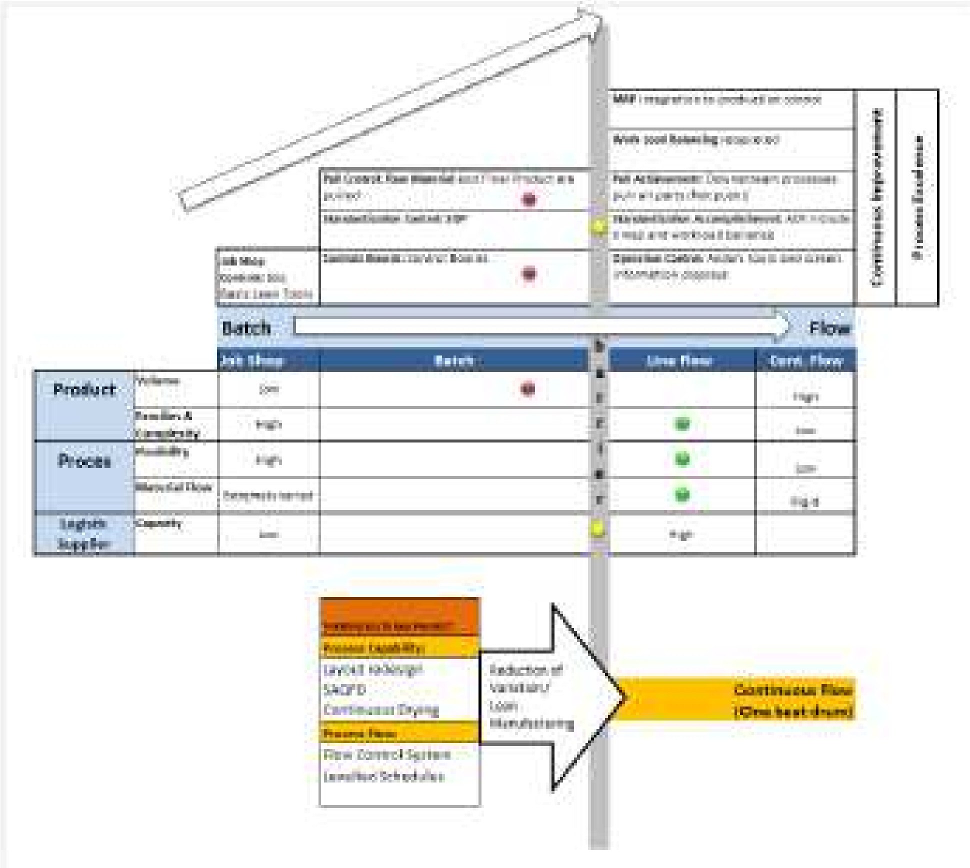

Figure 1: Batch / Flow Comparative Matrix

On the other hand, the product complexity and process flexibility provide great conditions for implementation of flow concept. Finally, there are two required improvements (yellow balls) in order to transpose from batch to flow. This novel analysis intent to envisage the best option to be considered during the concept design of the production line.

4.1 The Thermiculite 866 Production Line

After the conceptual definition the future Thermiculite 866 investment process is defined based in the requirements exposed in Figure 1. In addition, the following bullet points are important observations to define the guidelines in the definition, detailed design and implementation stages:

a. The DEMAND analysis (X thousand parts per year in 2015 in the UK) has defined that the process requires and improved drying process (manufacturing bottleneck) and automatization of the packaging process
b. THE PRODUCT and PROCESS are favourable to promote flow concepts and achieve the required high volume production levels. The Thermiculite 866 manufacturing can be summarized as the accurate spreading of wet material and posterior quick dry of this material. By adding more intermediate processes, only more waste would be obtained

5 INNOVATIVE DESIGN METHODOLOGY AND PROJECT PLANNING FOR THE HIGH VOLUME PRODUCTION LINE DESIGN

In fact there are two main reasons to use a specific manufacturing system. First, consider the mix and volume required to accomplish the demand. Second, recognize the output required in terms of cost, quality, performance, delivery, flexibility and innovativeness.
This paper intends to combine analysis of demand, facility design methods and project management techniques to develop the conceptual design of a high volume production line. Heaton (18) suggest that the design must consider the following strategies:

a. Take into account customer requirements
b. Take into account competitors
c. Take into account manufacturing capabilities
d. Consider all options available to manufacturing
e. List of the required outputs that manufacturing will provide

A more specific approach is suggested by Lee in Tompkins (19), who defines the following steps as part of the information, strategy and layout definition:

f. Strategy: Develop operational strategy and business architecture, define space planning units
g. Layout: Analyse material flow, calculate space, identify constrains
h. Product Analysis and Current Process: Display the current state value stream and definition of product family

In addition, Halen (20) suggest a plant layout analysis that includes a study of the production line flow charts, material flow diagrams, product routings, processing times, relationship diagrams between different departments in the facility and the cost of material movement.
The reader must understand that the development of a new production line or layout must not include only a process design but also the management during implementation. For this reason, The Proposed Conceptual Factory Planning Methodology needs a first stage of planning and a second stage of commercial awareness proposed by Heaton (18). In addition, it must include material flow and layout analysis as suggested by Tompkins (19)

and Halen (20). In addition, the characteristics and relationships defined in the SAQFD highlighted the necessity to incorporate a parallel Lean & Quality development process (16). Figure 2 displays the proposed model for high volume production line design and the required support from process development and equipment trials (grey flow line). Each section of the project (blue boxes in Figure 2) is defined by subtasks grouped according to different phases described by bullet points in page 6. The implementation of this structured process warranties the success of the project and the best Quality Assurance (QA) system and Lean implementation. In fact, the partition between conceptual design and detailed design represents the required Lean evaluation before continue with the future implementation.

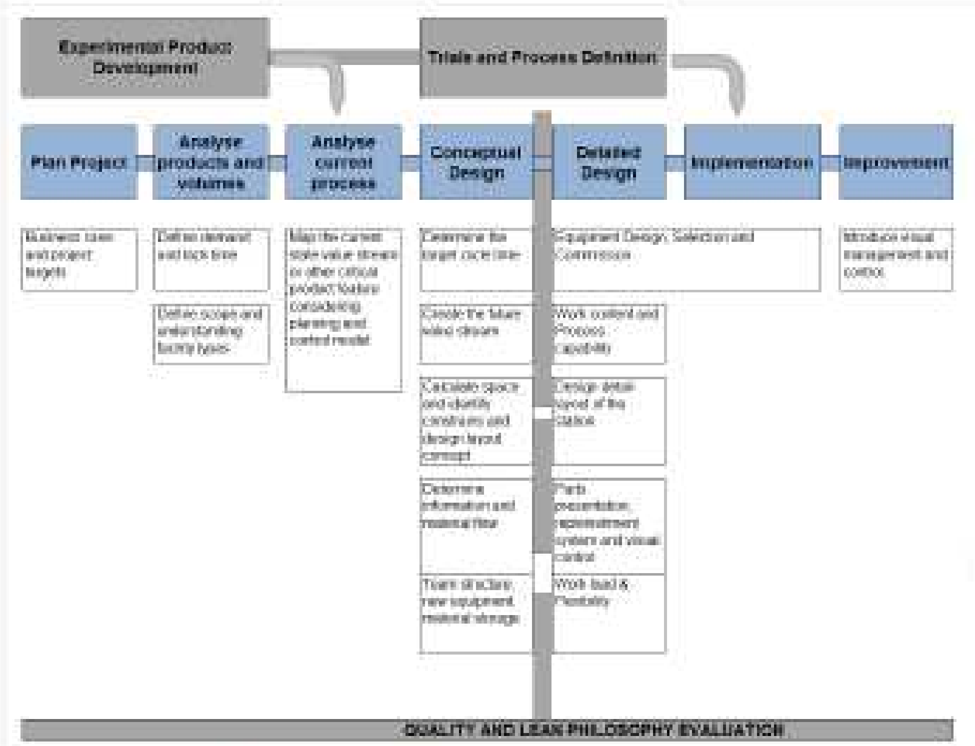

Figure 2: Proposed Conceptual Factory Planning Methodology

In the following section are listed the different outcomes from the Thermiculite 866 project. The author has included several specific outcomes and the date those were achieved or when it is expected to be finished. All the design and selection of equipment have gone through the process proposed in Figure 2. For example, the drying and packaging systems are currently in the detailed design stage and it is expected to be fully designed by the end of 2011. In addition, the mixer was already designed and implemented in Dec/2010. The reader must consider the following manufacturing processes as reference: Weight, Mix, Cast, Dry, Peel, Cut, Rolling and Packaging.

Plan Project: The project plan structure follows a logical implementation sequence which is based on the following organizational and managerial chapters: Team

Organization, Product Trials and Planning, Training, Production Line Design, Plant Preparation, In-Plant Build Activities and Continuous Improvement. The Thermiculite 866 Project Master Plan has achieved 18% (50 tasks) of the Gantt Chart tasks. The 300 tasks defined with the project Team aim to prepare Flexitallic for the Start of Production event in year 2015.

Analyse Product and Volumes: The Batch / Flow Comparative Matrix (Figure 1) provides the first approach to define the impact of the product features in the process. In addition, the Analysis of Volumes was performed during Demand & Manufacturing Strategies reviews that produced figures of manning, investment and line capacities. It was concluded that the batch process would require three times the manning required by the proposed line-flow equipment-paced.

Analyse Current Process: Due to the relative simple manufacturing process: Weight, Mix, Cast, Dry, Peel, Cut, Rolling and Packaging. It was not required to utilize all the extend of the Value Stream Mapping technique to recognize production bottle necks and improvement requirements. By 2015, the projected utilization of the process capabilities will be: 8% of Mix and Cast, 88% of Dry, 2% of Peel, Cut and Packaging. This means that all efforts should be directed to the drying process to achieve high volume capacities. In addition, the criticality of QA requires more attention for the control of variables such as mixing and drying times. For this reason, the team developed a mixing cycle control based on the "mixing energy" to register mix parameter and Weigh per Unit Area (WPUA) checks.

Conceptual Design: A SAQFD was developed to support the implementation of the entire Thermiculite 866 production line, although, its outcomes are focused in the Conceptual Design. In addition, the definition of the future target cycle time and value stream has been defined by the projected demand in the next five years. As explained above, 88% of the drying capacity would be used by 2015. The design of the modular drying solution and the "four conveyor" casting strategy will cope with the expected 200% acceleration slope. The four conveyor casting strategy intends to start extracting moisture by spreading the wet material just after mixing. Furthermore, considering the relative low drying temperature of 90 ºC, a drying time of less than 150 minutes can be achieved for Thermiculite 866 dough of 29.0 % solids. In Thermiculite 866 the aligned exfoliated vermiculite acts as an inorganic binder to bind all ingredients. As a result any microscopic paths that exist perpendicularly through the formed sheet have a very low degree of permeability and thus it is difficult for water vapour molecules to travel along them. This means that drying time cannot be reduced by increasing temperature because it causes blistering on the material surface. The "four conveyor" strategy intends to increase the drying capacity by increasing the drying area with a 90 ºC continuous drying solution. On the other hand, it has been defined the Plant Distribution and Layout that defined the material flow and equipment location to use the 600 square meter area for future increase of the drying capacity. Finally, it has been defined the strategy and general budget expenditure plan for the implementation of the Thermiculite 866 Equipment-Paced Line Flow during the next four years.

Detailed Design: Four gates have been defined before final approval of the equipment specifications and CAD drawings. These gates are: Concept Development and Trials, System Level Design and Detail Design. The intention is to engage the Technical Group, Operations and Compliance in the equipment selection and to promote communication, cooperation and "risk sharing". The success of the equipment design Current detailed design of drying solution will consider predetermined water content on conveyor band to extract water and reach 6% moisture content. The conceptual design and trials suggest modular design to facilitate future capacity expansion and the application of drying zone concept. In fact, the future Thermiculite 866 flow line will reach high volumes by using four parallel conveyors aligned to a pair of 90 °C continuous zoned ovens. Finally, the end line will cut and package cut rectangles of shaped gaskets.

Implementation: The implementation has been highly supported by trials and continuous communication with the equipment suppliers. In addition, Flexitallic defined payment terms and internal approbation gates to trial the technical specifications included in the supplier's proposal. As result, the vacuum mixer was designed, trailed and commissioned at Flexitallic.

Continuous Improvement: As explained in the Batch / Flow Comparative Matrix (Figure 1), Flexitallic needs to fill a gap to achieve the required production control to manage with the future high volume requirements. For this reason, the Flexitallic team requires to design, develop and implement the Thermiculite Business Plan according to the Flexitallic vision/mission and values: Quality, Production, H&S and PDCA Deming Cycle.

Experimentation and Trials: Most of the trials are based on testing one variable at a time, although, other multiple variation Taguchi methods may be explored in the future. There are number of trials that supported the detailed design and experimentation in 2010. For example, it was tested different concepts such as vacuum oven, zoned and continuous oven concept, and different types of mixers.

6 CONCLUSION AND RECOMMENDATIONS

This paper has defined an innovative methodology to design a high volume production line based on literature review and conceptualization of the flow line advantages. The Thermiculite 866 has already successfully implemented the conceptual design stage after the definition of the business requirements that started with the SAQFD developed by the authors.

The Batch / Flow Comparative Matrix (Figure 1) has successfully defined key parameters to analyze and define the requirement of product, process and supply to adopt flow concept to an specific production line. In addition, the matrix proposes clear Lean Manufacturing requirements to reach the required production control and obtain the real benefits of continuous flow.

The Proposed Conceptual Factory Planning Methodology (Figure 2) is the simplification of three different methodologies that consider the company strategy, material flow and layout design. The aim of this methodology is to promote cooperation and communication within different departments at the company and support every stage with experimentation.

The Thermiculite 866 case study provided a view of the application of the Batch / Flow Comparative Matrix and the methodology to define the gap between Batch and Flow. Finally, the Proposed Conceptual Factory Planning Methodology is the core of the Thermiculite 866 line design and the outcomes has been seen in the implementation of the project during 2010. The success of the proposed Methodology has been demonstrated with the current implementation of the Thermiculite 866 line.

The structured project management approach proposed in this study needs to be supported by training and communication strategies within the organization. The development of the Thermiculite 866 project required of continuous communication and training of people on shopfloor. In addition, it is important to mention that a robust organizational structure is fundamental to tackle every challenge with team synergy.

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APPENDIX 3

[illegible]							
		2.2.3	Contingency plan (Risk Assessment)	AH	06-Jul	TBD	A
		2.2.4	Quality Control sheets	AH	12-Jul	15-Oct	A
		2.2.5	Quality Control Definition (Inspection devices and process control loops)	RY/AH	12-Jul	30-Sep	O
2.3	Validation Plan for Manufacturing System and Subsystems	2.3.1	Lean Key statements and requirements	RY	12-Apr	19-Apr	A
		2.3.2	Mixing validation plan: Trials in BCH mixer	BCH	22-Nov	23-Nov	O
		2.3.3	Consolidation validation plan	BD	TBD	TBD	O
		2.3.4	Drying validation plan	RY	TBD	TDB	A
2.4	Product Design Release	2.4.1	Performance of risk assessment (FMEAs) with flexitallic	AH	14-Jun	TBD	A
		2.4.2	Definition of critical characteristics	AH	06-Jun	14-Jun	O
		2.4.3	Thermiculite 866 quality specifications	AH	07-Jun	TBD	A
2.5	Advanced Supplier Product Quality Planning	2.5.1	Evaluate the HTS suppliers and the CEV project as part of the Thermiculite 866 project	RY	18-Apr	29-Apr	A
2.6	Supply Chain Part Planning	2.6.1	Plan for every part	TA	02-May	27-May	A
C. Training							
3.0.	Integrated Training Plan (ITP) Developed and Implemented	3.0.1	Launch Training Cost Forecast	KN	TBD	TBD	A
		3.0.2	Prepare Preliminary Integrated Training Plan	KN	TBD	TBD	A
		3.0.3	Plan and training application (green belt to people on shop floor)	KN	07-Jan	11-Feb	A
		3.0.4	Ergonomic training for material manipulation	KN	TBD	TBD	A
3.1	Project Management	3.1.1	Management of the project by weekly short meetings	RY	05-Apr	TBD	O
		3.1.2	Review the Project Deliverables and sugestions	RY	05-Apr	26-Apr	O
3.2	Production Launch Team Workshop	3.2.1	5S and Lean Manufacturing	RY/CC/SN	20-Sep	TBD	A
		3.2.2	Couse effect (Ishikawa diagram) and BPD board definition	RY/SN	01-Nov	TBD	A
D. Production Line Design							
4.0.	System Capacity	4.0.1	Demand & Manufacturing Strategy	RY	07-Jun	06-Sep	O
		4.0.2	Bottle neck definition	RY	19-Apr	07-Jun	O
4.1	Flow VS Batch	4.1.1	Batch VS continuous flow: manning, investment, capacities, etc	RY	02-Aug	13-Sep	O
4.2	Layout	4.2.1	Layouts and process flow schemes result in Optimal Material Flow	RY	27-Sep	25-Oct	O
		4.2.2	Include in the layout the future 835 expansion	SL/RY	04-Oct	11-Oct	O
		4.2.3	Lean design and evaluation of facilities, equipment, tooling and layout for the purpose of minimizing capital requirements. The seven forms of waste (Correction, Overproduction, Material Movement, Motion, Waiting, Inventory, Processing)	RY	25-Oct	TBD	A
		4.2.4	Health and safety assessment	RY	18-Oct	20-Jan	A
E. Plant Preparation							
5.0.	Manufacturing System Installation Completed	5.0.1	Manufacturing system installed according to installation: Conveyors, robots, tools, etc., are in place layout and plan Manufacturing system installed according to installation layout and plan	RY	07-Mar	27-Jun	A
		5.0.2	System for dimensional data measuring and data collection established	RY/AH	06-Jun	27-Jun	A
		5.0.3	Tooling/engineering drawings media defined for plant hand-off	RY/SN	01-Nov	10-Jan	O
		5.0.4	CEV and HTS inventory controlled and optimized	TA	06-Jun	27-Jun	A
		5.0.5	Manufacturing system is ready for Manufacturing Validation Builds (MVB)	RY	27-Jun	04-Jul	A
		5.0.6	All 866 technical documentation available	RY	20-Jun	27-Jun	A
		5.0.7	Production Maintenance (PM) plan defined, ready to start execution	BD	27-Jun	04-Jul	A
		5.0.8	Daily construction meetings	RY	06-Dec	27-Jun	A
		5.0.9	Weekly report of the Manufacturing Validation Build	RY	04-Jul	31-Oct	A
		5.0.10	Total Productive Maintenance (TPM): Considering operation times	BD	01-Aug	29-Aug	A
5.1	Conveyor Clearance and Other Facility Issues Validated	5.1.1	Conveyor clearance checked and corrected	SN	TBD	TBD	A
		5.1.2	Validate transportation modes for adequate clearances for all 866 products	TA	TBD	TBD	A
		5.1.3	Work station details of tooling and visual management	SN	10-Sep	26-Sep	A
		5.1.4	Lifts devices and ergonomic awareness	DB	04-Oct	TBD	A
4.2	Launch Operations Board	4.2.1	Internal SOFC presentation and project launch	RY	19-Nov	19-Nov	A
		4.2.2	Define centre for design and on shop meetings	RY	19-Nov	04-Dec	A
		4.2.3	Plant layout posted	RY	TBD	TBD	A
		4.2.4	Launch team organization, members' list and phone and pager numbers posted	ST	TBD	TBD	A
		4.2.5	Plant support contacts and phone and pager numbers available	ST	TBD	TBD	A
		4.2.6	Sign-in board for the team and visitors	ST	TBD	TBD	A
		4.2.7	Thermiculite 866 Build schedule posted	RY	TBD	TBD	A
		4.2.8	Build Status Wall	RY	TBD	TBD	A
		4.2.9	Launch team meetings: Agenda	RY	TBD	TBD	A
		4.2.10	Problem communication, resolution and documentation procedures	ST	TBD	TBD	A
		4.2.11	Suppliers risk assessment status chart	TA	TBD	TBD	A
		4.2.12	Management of the project by weekly short meetings	RY	TBD	TBD	A
4.3	Initial Line Balance for Manufacturing Validation Builds	4.3.1	Operation sequence completed	SN	08-Nov	TBD	A
		4.3.2	Open issues identified and listed	SN	08-Nov	TBD	A
		4.3.3	List of tooling, location and 5S	SN	08-Nov	TBD	A
		4.3.4	Baseline Process Flow Diagram	AH	08-Nov	TBD	A
		4.3.5	Supply Chain Part Planning (SCPP)	TA	08-Nov	TBD	A
		4.3.6	Workcell layout (Zone or S.L.) completed	SN	08-Nov	TBD	A
		4.3.7	Ergonomic Evaluation sheet completed	DB/KN	08-Nov	TBD	A
4.4	Installation of Hand Tools, Racks, etc.	4.4.1	Line address signs, Operator Certification Boards, and Visual Controls	SN	20-Jun	27-Jun	A
		4.4.2	Report status at Manufacturing Validation PQRR Review	RY	04-Jul	11-Jul	A
		4.4.3	Error proofing equipment installed	TBD	04-Jul	11-Jul	A
4.5	Supplier Launch Readiness Process (CEV project)	4.5.1	Overall program timing	TA	15-Dec	TBD	A
		4.5.2	Manufacturing system layout	RY	15-Dec	TBD	A
		4.5.3	Process Flow Diagram	TA	15-Dec	TBD	A
		4.5.4	Process Control Plan	TA	15-Dec	TBD	A
		4.5.5	Process Failure Mode and Effects Analysis completed	AH	15-Dec	TBD	A
		4.5.6	Part quality targets planned and agreed upon	TA	15-Dec	TBD	A
		4.5.7	Assembly fixture concept complete/agreed part checking	TA	15-Dec	TBD	A
		4.5.8	Material packaging plan complete	TA	15-Dec	TBD	A
		4.5.9	Program Risk Analysis	TA	15-Dec	TBD	A
4.6	Standardization	4.6.1	Process Detail & Tack time	AH/SN	02-May	09-May	A
		4.6.2	Scrap and rework process	RY/AH	16-May	30-May	A
		4.6.3	Critical processes (Fire and substances)	DB	02-May	16-May	A
		4.6.4	Visual management and 5 S	SN	13-Jun	27-Jun	A
		4.6.5	House keeping and tools management	SN	13-Jun	27-Jun	A
4.7	Quality	4.7.1	Quality Standards	AH	16-May	TBD	A
		4.7.2	Process Controls (Production control board)	AH	16-May	TBD	A
		4.7.3	Discrepancies identification	AH	16-May	TBD	A
		4.7.4	Comunication and Feedback process	AH	16-May	TBD	A
		4.7.5	Production Capacity and restrictions defined	AH	16-May	TBD	A
		4.7.6	Proper conveyance methods stablished	AH	16-May	TBD	A
		4.7.7	Process to manage exceptions (assistance)	AH	16-May	TBD	A
4.8	Production and inventory	4.8.1	Buffers Definition and raw material delivery	BB	23-May	27-Jun	A
		4.8.2	Warehouse Layouts	BB	23-May	27-Jun	A
		4.8.3	Plan for HTS and Talk raw material	BB	23-May	27-Jun	A
		4.8.4	Equipment for manipulation	BB	23-May	27-Jun	A
		4.8.5	Pull System and Replenishment Method	BB	23-May	27-Jun	A
		4.8.6	Production control boards	BB	23-May	27-Jun	A
		4.8.7	Packing and Shipping processes	BB	23-May	27-Jun	A
		4.8.8	5s on shipment and reception	BB	23-May	27-Jun	A
4.9	Accounting procedures	4.9.1	Work orders	MH	08-Aug	29-Aug	A
		4.9.2	Account numbers	MH	08-Aug	29-Aug	A
		4.9.3	Approval procedure	MH	08-Aug	29-Aug	A
		4.9.4	Tracking	MH	08-Aug	29-Aug	A
		4.9.5	Build combinations in system	MH	08-Aug	29-Aug	A
4.10.	Installation of Hand Tools, Racks, etc.	4.10.1	Racks validation by quality	BB	TBD	TBD	A
		4.10.2	Validation pull visuals	BB	TBD	TBD	A
4.11.	Supplier Communications Plan Completed	4.11.1	Comunication with all the Equipment Suppliers	RY	04-Oct	21-Mar	A
		4.11.2	Comunication with the HTS suppliers	TA	17-Jan	21-Mar	A
4.12.	Supply Chain Part Planning	4.12.1	HTS and CEV supply plan	RY	05-Sep	26-Sep	A
4.13.	Develop & Maintain Assembly Process Visual	4.13.1	Lay out displayed on shop floor	RY	18-Oct	27-Jun	A
4.14.	Safety compliance verification plan	4.14.1	Chemical/Physical safety plan	DB	04-Apr	25-Apr	A
		4.14.2	Material Safety Data Sheets	DB	04-Apr	25-Apr	A
		4.14.3	Safe job instructions	DB/SN	02-May	16-May	A
F. In-Plant Build Activities							
5.0.	Matching Process	5.0.1	The Matching Evaluation (demand and equipment capacity)	RY	07-Feb	28-Feb	A
		5.0.2	Line control process and interlocks (Meet BD)	BD	01-Nov	06-Dec	A
		5.0.3	Software Support System	GB	03-Jan	01-Aug	A
		5.0.4	Develop manufacturing capability database to store information	GB	03-Jan	01-Aug	A
		5.0.5	The Integration Matching (Dimensional fit and perceived quality learnings are generated from prototype tooled parts and processes.)	RY	07-Feb	28-Feb	A
		5.0.6	Matching #1 (M1): Mixing - Casting (quick fitting release and valves)	RY	11-Oct	15-Nov	A
		5.0.7	Matching #2 (M1): Casting - Drying	RY	TBD	TBD	A
		5.0.8	Matching #3 (M1): Drying - Cutting	RY	TBD	TBD	A
5.1	Mixer Selection and Tryout		Mixer Specification				
		5.1.1	Mixer Specifications	JH/RY	05-Jul	13-Sep	A
		5.1.2	Trials	JH	05-Jul	30-Aug	O
			Mixer Selection and Commission				
		5.1.3	Quotation and first proposal from supplier	Supplier	NA	NA	O
		5.1.4	Civil construction requirements and shop floor modifications for water waste disposal (drawings)	BD	11-Oct	06-Dec	A
		5.1.5	Electrical wiring and appliances	BD	11-Oct	18-Oct	O
		5.1.6	Operation and maintenance: BCH Funtional Design Specification	BD	TBD	TBD	A
		5.1.7	Health and safety validation	DB	14-Sep	06-Oct	O
		5.1.8	Legal and environmental concerns (Waste disposal system)	DB	14-Sep	06-Oct	O
		5.1.9	Pumping system for waste material	RY	TBD	TBD	A
		5.1.10	CAPEX (Equipment and associated cost)	RY	NA	NA	O
		5.1.11	Drawing approval: VP, Quality, Manufacturing, H&S and SC	RY	06-Oct	06-Oct	O
			Process capability assessed				
		5.1.12	Preliminary tool repeatability and reproducibility established	RY	15-Sep	15-Dec	A
		5.1.13	Tooling throughput bottlenecks identified	RY	15-Sep	15-Dec	A
		5.1.14	Cycle time verified	RY	15-Sep	15-Dec	A
		5.1.15	Error proofing verified	RY	15-Sep	15-Dec	A
		5.1.16	Mixing requirements in place	RY	15-Sep	15-Dec	A
			Build quality issues identified and resolved				
		5.1.17	Tools and equipment identified to warranty quality: Checklist QD	TH	01-Dec	10-Dec	A
		5.1.18	Development of the WPUA vs blade setting curve				
		5.1.19	Safety and ergonomics issues in the production environment identified and resolved	DB	01-Dec	10-Dec	A
			Operator Readiness				
		5.1.20	Training defined in the Integrated Training Plan complete or scheduled for completion	RY	TBD	TBD	A
		5.1.21	Job instruction finalized and complexity established	RY	TBD	TBD	A
		5.1.22	Simulation or floor experience for "hands on" repetition with leaders, coordinators, and operators	RY	TBD	TBD	A
5.2	Casting Tryout		Mixer Specification				
		5.2.1	COMAC Equipment Specifications	JH	NA	NA	O
		5.2.2	Trials	JH	NA	NA	O
			Process capability assessed				
		5.2.3	Preliminary tool repeatability and reproducibility established	RY	TBD	TBD	A
		5.2.4	Tooling throughput bottlenecks identified	RY	TBD	TBD	A
		5.2.5	Cycle time verified	RY	TBD	TBD	A
		5.2.6	Error proofing verified	RY	TBD	TBD	A
		5.2.7	Gauging requirements in place	RY	TBD	TBD	A
			Build quality issues identified and resolved				
		5.2.8	Conveyor quotations from three different suppliers	RY	10-Oct	15-Dec	A
		5.2.9	Tools and equipment checked for cycle time	RY	12-Sep	12-Dec	A
		5.2.10	Civil construction requirements and shop floor modifications (drawings)	BD	03-Jan	17-Jan	A
		5.2.11	Safety and ergonomics issues in the production environment identified and resolved	DB	03-Jan	14-Mar	A
		5.2.12	Conveyor drawing approval: VP, Quality, Manufacturing, H&S and SC	DB	24-Jan	21-Feb	A
			Operator Readiness				
		5.2.13	Training defined in the Integrated Training Plan complete or scheduled for completion	RY	TBD	TBD	A
		5.2.14	Job instruction finalized and complexity established	RY	TBD	TBD	A
		5.2.15	Simulation or floor experience for "hands on" repetition with leaders, coordinators, and operators	RY	TBD	TBD	A
		5.2.16	Customs requirements identified for shipping equipment and materials across international borders	RY	TBD	TBD	A
5.3	Drying system		Oven Specification				
		5.3.1	Oven Specifications	JH/RY	19-Jan	TBD	A
		5.3.2	Trials	RY	19-Jan	TBD	A
			Oven Selection and Commission				
		5.3.3	Quotation and first proposal from supplier	RY	10-Jan	14-Mar	A
		5.3.4	Internal approval of the design and the drawings	All	TBD	TBD	A
		5.3.5	Update of requirements and modification of the first proposal	RY	TBD	TBD	A
		5.3.6	Civil construction requirements and shop floor modifications (drawings)	RY	TBD	TBD	A
		5.3.7	Electrical facilities requirements: Electrical Wiring Diagrams	BD	TBD	TBD	A
		5.3.8	Gas distribution system	BD	TBD	TBD	A
		5.3.9	Operation and maintenance	BD	TBD	TBD	A
		5.3.10	Health and safety validation	DB	TBD	TBD	A
		5.3.11	Legal and environmental concerns	DB	TBD	TBD	A
		5.3.12	CAPEX (Equipment and associated cost)	DM	TBD	TBD	A
		5.3.13	Drawing approval: VP, Quality, Manufacturing, H&S and SC	DB	TBD	TBD	A
			Process capability assessed				
		5.3.14	Preliminary tool repeatability and reproducibility established	RY	TBD	TBD	A
		5.3.15	Tooling throughput bottlenecks identified	RY	TBD	TBD	A
		5.3.16	Cycle time verified	RY	TBD	TBD	A
		5.3.17	Error proofing verified	RY	TBD	TBD	A
		5.3.18	Gauging requirements in place	RY	TBD	TBD	A
			Build quality issues identified and resolved				
		5.1.19	Tools and equipment checked for cycle time	RY	TBD	TBD	A
		5.1.20	Safety and ergonomics issues in the production environment	RY	TBD	TBD	A
			Operator Readiness				
		5.1.21	Training defined in the Integrated Training Plan complete or scheduled for completion	RY	TBD	TBD	A
		5.1.22	Job instruction finalized and complexity established	RY	TBD	TBD	A
		5.1.23	Simulation or floor experience for "hands on" repetition with leaders, coordinators, and operators	RY	TBD	TBD	A
		5.1.24	Customs requirements identified for shipping equipment and materials across international borders	RY	TBD	TBD	A
5.4	Consolidation system		Calendar Specification				
		5.4.1	Calendar or Roller Specifications	JH/RY	05-Jul	20-Sep	O
		5.4.2	Trials	RY	05-Jul	13-Sep	O
			Consolidation Selection and Commission				
		5.4.3	Quotation and first proposal from supplier	Supplier	NA	NA	A
		5.4.4	Manufacturing system integration (hardware and software) completed: Implementation of DECADE 260 series for pressing control	RY	02-May	30-May	A
		5.4.5	Internal approval of the design and the drawings	All	NA	NA	A
		5.4.6	Update of requirements and modification of the first proposal: CAPEX approval after visit JBT	DM/JH	25-Oct	25-Oct	A
		5.4.7	Civil construction requirements and shop floor modifications (drawings)	RY	TBD	TBD	A
		5.4.8	Electricity facilities requirements: Electrical Wiring Diagrams	BD	TBD	TBD	A
		5.4.9	Operation and maintenance	BD	13-Oct	13-Oct	O
		5.4.10	Health and safety validation	DB	13-Oct	13-Oct	O
		5.4.11	Legal and environmental concerns	DB	13-Oct	13-Oct	O
		5.4.12	CAPEX (Equipment and associated cost)	JH	TBD	TBD	A
		5.4.13	Conveyor drawing approval: VP, Quality, Manufacturing, H&S and SC	RY	TBD	TBD	A
			Process capability assessed				
		5.4.14	Preliminary tool repeatability and reproducibility established	RY	TBD	TBD	A
		5.4.15	Tooling throughput bottlenecks identified	RY	TBD	TBD	A
		5.4.16	Cycle time verified	RY	TBD	TBD	A
		5.4.17	Error proofing verified	RY	TBD	TBD	A
		5.4.18	Gauging requirements in place	RY	TBD	TBD	A
			Build quality issues identified and resolved				
		5.4.19	Tools and equipment checked for cycle time	RY	TBD	TBD	A
		5.4.20	Safety and ergonomics issues in the production environment identified and resolved	RY	TBD	TBD	A
			Operator Readiness				
		5.4.21	Training defined in the Integrated Training Plan complete or scheduled for completion	DB	TBD	TBD	A
		5.4.22	Job instruction finalized and complexity established	RY	TBD	TBD	A
		5.4.23	Simulation or floor experience for "hands on" repetition with leaders, coordinators, and operators	RY	TBD	TBD	A
		5.4.24	Customs requirements identified for shipping equipment and materials across international borders	RY	TBD	TBD	A
5.4	Quality System Tryout		Process capability assessed				
		5.4.1	Preliminary gauge repeatability and reproducibility established for 100% inspection, Quality Assurance, and process monitoring activities	TH	TBD	TBD	A
		5.4.2	Data collection and reporting systems assessed for all Quality processes	TH	TBD	TBD	A
		5.4.3	Cycle time define and verified	RY	TBD	TBD	A
		5.4.4	Verification stations, Customer Audits, Monitoring, and Squeak and Evaluation track tryout	TH	TBD	TBD	A
		5.4.5	Assure operators know equipment operation, root cause and problem communication processes	TH	TBD	TBD	A
			Product Quality standard issues identified and resolved	TH	TBD	TBD	A
			Safety and ergonomics issues identified and resolved	DB	TBD	TBD	A
		5.4.6	Training defined in the Integrated Training Plan complete or scheduled for completion	RY	TBD	TBD	A
		5.4.7	Job instruction finalized and complexity established	RY	TBD	TBD	A
		5.4.8	Operator Certification is tracked on versatility charts	RY	TBD	TBD	A
5.5	Operation Readiness and Certification Operation Readiness and Certification is a standardized process that utilizes the Plan, Do, Check, Act principles which verify workstations and processes are set up properly, and provides a method to measure and track plant readiness.	5.5.1	Implementation Plan	RY	TBD	TBD	A
5.6	Manufacturing Validation Builds (MVB) Successful execution of this activity will significantly reduce the Lost 1. Controlled rigorous system to match all the equipments capacities and tack times. 2. Iterative problem-solving to minimize the number of build issues at SORP 3. Skill up the production organization/line operators Production Days During Launch and Duration of Acceleration, two key business metrics that are part of the program contract	5.6.1	Define MVB building activities	RY	TBD	TBD	A
		5.6.2	MVB : Standard CERES product	RY	TBD	TBD	A
5.7	Operation Readiness and Certification	5.7.1	Thermiculite 866 Technical Specifications (TTS's) are known and understood	RY	TBD	TBD	A
		5.7.2	Surface Validation Process	RY	TBD	TBD	A
		5.7.3	Perceived Quality and feedback (from CERES)	RY	TBD	TBD	A
5.8	Planned acceleration curves should be at 70 percentile performance.	5.8.1	Acceleration curves	RY	TBD	TBD	A
5.9	Validate Material Flow and Shipping Plan	5.9.1	Facilities Layout (Material)	RY	20-Sep	25-Oct	O
		5.9.1.1	Material Storage Areas Correctly Sized	RY	22-Nov	15-Aug	A
		5.9.1.2	All Aisles and Lineside Approaches allow proper route sheets	RY	TBD	TBD	A
		5.9.2	Container Validation	RY	TBD	TBD	A
		5.9.2.1	Operator Friendly & Ergonomically Correct Packaging	RY	TBD	TBD	A
		5.9.2.2	Container and Dunnage Handling Plan Complete	RY	TBD	TBD	A
		5.9.2.3	Lot Size Minimized	RY	TBD	TBD	A
		5.9.3	Logistics Validation	RY	TBD	TBD	A
		5.9.3.1	Delivery Routes Optimized	RY	TBD	TBD	A
		5.9.3.2	Receiving Windows Scheduled	RY	TBD	TBD	A
		5.9.3.3	Externally Dock Plan and Utilization is Complete	RY	TBD	TBD	A
		5.9.3.4	Carrier Service Responsibilities Established	RY	TBD	TBD	A
		5.9.3.5	Transportation Mode Determined	RY	TBD	TBD	A
		5.9.3.6	Frequency Established	RY	TBD	TBD	A
		5.9.4	Dock to Operator Elements	RY	TBD	TBD	A
		5.9.4.1	Internal Dock Plan & Utilization Functional	RY	TBD	TBD	A
		5.9.4.2	Visual Controls Posted in Storage Areas	RY	TBD	TBD	A
		5.9.4.3	Discrepant Material Procedures Validated	RY	TBD	TBD	A
		5.9.4.4	Material Tracking Handoff Process Complete	RY	TBD	TBD	A
		5.9.5	Material Readiness Checklist	RY	TBD	TBD	A
		5.9.5.1	HTS and talk Lineside Presentation	RY	TBD	TBD	A
		5.9.5.2	Flow Rack Optimized	RY	TBD	TBD	A
		5.9.5.3	Visual Controls Correct	RY	TBD	TBD	A
		5.9.5.4	Loop Size Verified	RY	TBD	TBD	A
		5.9.5.5	Mobile Equipment Requirements Verified	RY	TBD	TBD	A
		5.9.5.6	Material Routings Correct	RY	TBD	TBD	A
		5.9.5.7	Material Pull Signal Functional	RY	TBD	TBD	A
5.9	Test and Audit	5.9.1	Prepare check sheets for static and dynamic checks	RY	TBD	TBD	A
		5.9.2	Assure facilities are provided	RY	TBD	TBD	A
		5.9.3	Auditors are trained and have work instructions	RY	TBD	TBD	A
		5.9.4	Platform conference calls sharing daily results (where appropriate)	RY	TBD	TBD	A
G. Consolidation and Improvement							
6.0.	Lean Manufacturing Implementation	6.0.1	Post implementation review and improvement process	All	TBD	TBD	A
		6.0.2	Review the Project Deliverables and sugestions	All	TBD	TBD	A
		6.0.3	Review the result of the sustainment system	All	TBD	TBD	A
		6.0.4	Inspection test plan/buy off document improvement	All	TBD	TBD	A
		6.0.5	Dispose tools not required and update list of tools	All	TBD	TBD	A
		6.0.6	Learn lessons and Correction	All	TBD	TBD	A